Synthetic Theater of War-Europe (STOW-E) Technical Analysis

C. M. Keune D. Coppock

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Naval Command, Control and
Ocean Surveillance Center
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ADMINISTRATIVE INFORMATION

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SB

EXECUTIVE SUMMARY

BACKGROUND

The Synthetic Theater of War-Europe (STOW-E) distributed simulation demonstration was conducted 4–7 November 1994. This exercise linked 16 sites around the world in a single virtual battlespace. Live, virtual, and constructive forces representing all four Department of Defense (DoD) services participated in a joint operation involving land, sea, and air engagements.

STOW-E was executed over the Defense Simulation Internet (DSI). The limiting factor in network capacity was 1.1 Mbps tail circuits. To fit within this limit, an Application Gateway (AG) housing seven bandwidth-demand reduction techniques (BRTs) was developed to reduce the participating simulations' traffic. At each site directly connected to the DSI, an AG operated between DSI's wide area network (WAN) and the local area networks (LANs). The seven BRTs were as follows:

1. Grid Filtering
2. Quiescent Entity Determination (QED)
3. Protocol Independent Compression Algorithm (PICA)
4. Bundling
5. Fidelity Control
6. Protocol Data Unit (PDU) Culling
7. LAN Filtering

STOW-E technical analysis issues fall into the following three categories:

1. AG performance
2. DIS traffic characterization
3. Network traffic delays

AG PERFORMANCE

Pre-STOW-E analysis indicated that the AG had to provide a four-fold bit reduction. Post-analysis showed that the real requirement was closer to a three-fold bit reduction. The AG median bit reduction was 5.5. The heavy loads transmitted from the STOW-E Engineering and Analysis Facility (SEAF) and Simulation Network (SIMNET) sites in Grafenwoehr, GE, were the critical ones requiring reduction. The median bit reduction at the SEAF was 10.5 and at SIMNET was 13.5.

Table 1 lists the median reduction factors (RF) in bits and packets observed for each site. The table also contains the values used to calculate the reduction factor ratios. The median of the RF (Kbps) is 5.5, and the simple mean is 5.9. The mean RF (Kbps) weighted by LAN load is 10.6.

The wide range of reduction factors observed is a function of the different types and loads of generated traffic. The AG reduction factors are highest for heavy traffic loads generated by passive entities. Reduction factors less than 1.0 indicate more outgoing traffic on the WAN side of the AG than on the LAN side. The additional WAN traffic is AG-to-AG control traffic. Note that if the AG contributed more traffic to the WAN than it reduced; for example, at Naval Air Warfare Center–Aircraft Division (NAWC–AD), the site DIS LAN load generated was very light.

Table 1. Median AG reduction factors.

Sites	LAN Load (pps)	LAN Load (Kbps)	WAN Load (pps)	WAN Load (Kbps)	RF (pps)	RF (Kbps)
NAWC–AD	3.7	4.3	3.3	8.6	1.1	0.5
WISSARD	88.9	106.8	2.9	66.8	30.5	1.6
TACTS	0.6	0.7	2.8	0.4	0.2	1.9
TACCSF	48.1	57.5	3.5	20.5	13.9	2.8
NUWC	4.8	5.5	3.0	0.7	1.6	8.1
AVTB	6.9	8.7	0.1	1.1	54.8	8.1
SEAF	263.7	310.5	3.1	29.6	83.8	10.5
SIMNET	347.9	508.6	4.9	37.7	71.3	13.5

DISTRIBUTED INTERACTIVE SIMULATION (DIS) TRAFFIC

The DIS traffic generation rates of different entity types showed great variability. This was also true among similar entity types generated by different simulations. As expected, generation rates also varied significantly with scenario. Nevertheless, a load prediction worksheet was compiled based on these traffic analyses. The rates for various entity types are shown in table 2. (Note that these numbers reflect the STOW-E finding that 81% of the packet load and 71% of the bit load were due to Entity State Protocol Data Units (ESPDUs). This lower ESPDU load was due to the numerous experimental PDUs generated by the Battalion/Brigade Battle Simulation (BBS).)

Table 2. Data generation prediction values based on STOW-E.

Entity Type	Rate (pps)	Rate (Kbps)
Submarine	0.62	1.09
Ship	0.49	1.16
Fixed-Wing Aircraft (FWA)	2.10	3.72
Rotary-Wing Aircraft (RWA)	1.36	2.40
Tank	0.62	1.27
Truck	0.62	1.09
Dismounted Infantry (DI)	0.62	1.09

NETWORK DELAYS

Delays through the Aviation Test Bed (AVTB) AG, across the DSI, and through the SIMNET AG were estimated for four samples. Mean delay through the AG ranged from 0.18 to 1.51 seconds (s). Of the eight estimates, six were less tha 0.50 s and two were greater than 1.00 s. Only one of the longest delays were associated with a heavier LAN load. The mean delays across the DSI ranged from 0.10 to 0.20 s, reasonable delays for a transatlantic hop. The absence of clock synchronization among the machines logging this data greatly increased the complexity of the estimation process and decreased the estimates' quality.

End-to-end delays were estimated among the Naval Undersea Warfare Center (NUWC), the Tactical Air Combat Training System Facility (TACCSF), and the Naval Air Warfare Center–Aircraft Division (NAWC–AD). The data loggers at these three Red sites were all time-synchronized using Global Positioning System (GPS) receivers. Mean delays ranged from 1.02 to 5.03 s. This was greater variability than was anticipated. No packet loss over the DSI was observed.

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1. INTRODUCTION

1.1 BACKGROUND

The Synthetic Theater of War–Europe (STOW–E) distributed simulation demonstration was conducted 4–7 November 1994. This exercise linked 16 sites around the world in a single virtual battlespace. Live, virtual, and constructive forces representing all four DoD services participated in a joint operation involving land, sea, and air engagement.

One of the critical technologies demonstrated in the STOW–E was Scaleability. The goal of the Scaleability effort was to support the evolution of Distributed Interactive Simulation (DIS) technology by pushing back the limitations on the number of entities that could participate in an exercise. The Scaleability challenge for STOW–E was to reduce the traffic generated by the participating simulations to the 1.1 megabit-per-second (Mbps) capacity of the tail circuits of the Defense Simulation Internet (DSI). The Scaleability solution was to reduce the DIS traffic load offered to the DSI wide area network (WAN) by using seven bandwidth-demand reduction techniques (BRTs). The algorithms were as follows:

1. Protocol Data Unit (PDU) Culling
2. Broadcast Grid Filtering
3. Quiescent Entity Determination (QED)
4. Protocol Independence Compression Algorithm (PICA)
5. Bundling
6. Overload Management
7. LAN Filtering

These algorithms were housed in Application Gateways (AG) that operated in series between the DSI WAN and the simulation LAN (ETA/ATI, 1994).

1.2 OVERVIEW

This report presents the technical analysis of the Scaleability performance data collected during STOW–E. Section 2 describes the tools used to collect the data, the configuration of these tools at the various sites, and how the STOW–E DSI bandwidth was allocated. Section 3 describes the data management and analysis process. Section 4 contains the results and discussion. Lessons learned are presented in section 5, and conclusions are presented in section 6. Acronyms are in section 8. The appendices contain more detailed results of the data analysis.

2. COLLECTION

2.1 THE COLLECTION TOOLS

The data upon which these analyses are based were collected using the Naval Command, Control and Ocean Surveillance Center (NCCOSC), RDT&E Division (NRaD), Distributed Interactive Simulation (DIS) Protocol Data Logger (Dlogger), the NRaD AGWANLogger (WANLogger), and the Bolt, Beranek, and Newman (BBN) Advanced Network Monitor (ANM). Dlogger records all DIS traffic on a simulation LAN. The WANLogger, a modified version of the Dlogger, records the network traffic on the WAN side of the AG. Dlogger and WANLogger were both run on Silicon Graphics (SGI) platforms. BBN's ANM was capable of monitoring more than 50 points across the DSI network. Statistics available from ANM included total load in bytes, packet count, error count, and discard count for each sampling interval.

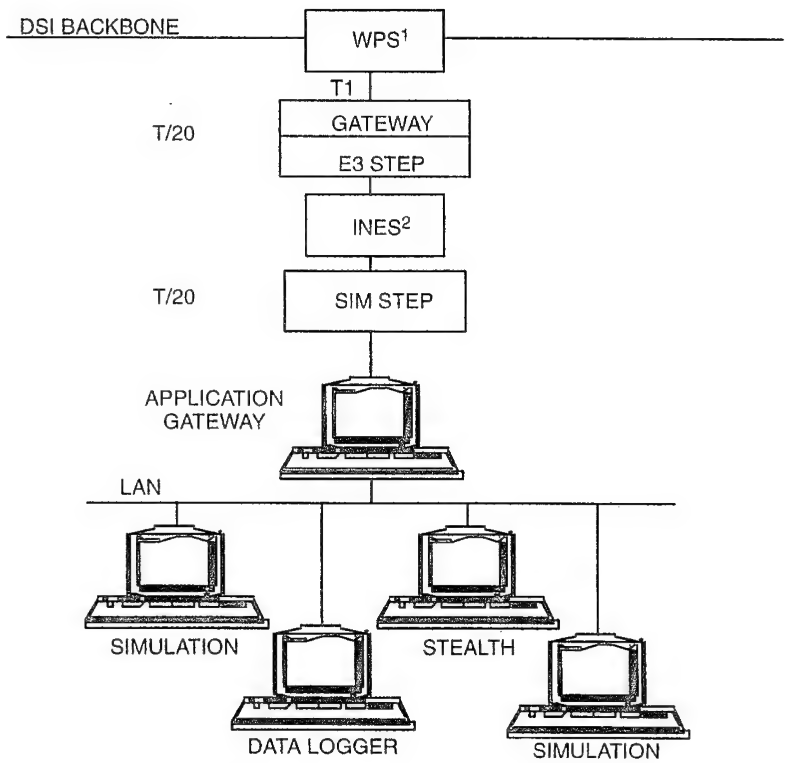
2.2 CONFIGURATIONS

2.2.1 Red Sites

STOW–E included the following nine Red (Encrypted) sites directly connected to the DSI: Battle Force Tactical Trainer (BFTT), Dam Neck, VA; Institute for Defense Analyses (IDA), Alexandria, VA; Naval Air Warfare Center-Aircraft Division (NAWC–AD), Patuxent River, MD; Naval Undersea Warfare Center (NUWC), Newport, RI; STOW–E Engineering and Analysis Facility (SEAF), Grafenwoehr, GE; Tactical Air Combat Training System Facility (TACCSF), Kirtland Air Force Base (AFB), NM; Tactical Aircrew Combat Training System (TACTS), Cherry Point, NC; Naval System Warfare Center – Dahlgren Division (NSWC-DD), Dahlgren, VA; and What If Simulation Systems for Research and Development (WISSARD), Naval Air Station (NAS) Oceana, VA. "Backdoor sites" (sites connected via other networks to a principal site's LAN) included Royal Air Force (RAF), Lakenheath, UK; Theater Battle Arena (TBA), Pentagon, Washington, DC; United States Air Force (USAF) Armstrong Lab, Mesa, AZ; and USS Hue City, Mayport, FL. The Dlogger was used to record the DIS traffic on the simulation LANs at these sites, with two exceptions. There was no Dlogger at Dahlgren, and, due to technical problems, there were no Dlogger records from Dam Neck. ANM recorded summary data at the end-to-end encryption (E-3) STREAM II Encapsulated Protocol (STEP) boards at each Red site. Figure 2-1 illustrates the configuration of a typical Red STOW–E site.

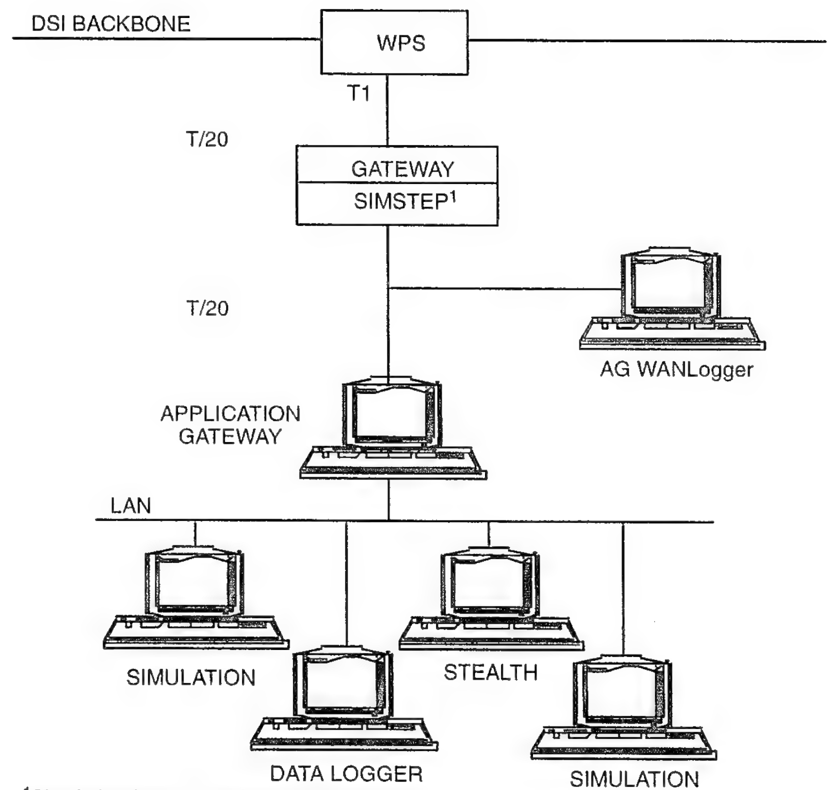
2.2.2 Black Sites

STOW–E included two Black (Unencrypted) sites connected directly to the DSI without intermediate encryption gear. They were the Aviation Test Bed (AVTB) at Ft. Rucker, AL, and the Simulation Network (SIMNET) simulator suite at Grafenwoehr, GE. The Battalion/Brigade Battle Simulation (BBS) and the Combat Maneuver Training Center – Instrument System (CMTC–IS) Hohenfels, GE, were backdoor sites to Grafenwoehr, GE. Dlogger was used to record the DIS traffic on the simulation LANs at both sites; WANLogger was used to record the DIS traffic on the WAN side of the AG at each site. Figure 2-2 illustrates the equipment configuration at the Black STOW–E sites. It should be noted that the presence of a unidirectional data-link between SIMNET (Black) and the STOW–E Engineering and Analysis Facility (SEAF) (Red) enabled Black simulation traffic to be injected onto the Red simulation network without compromising the security of the encrypted portion of the STOW–E demonstration.



[1]Wideband Packet Switch
[2]Improved Network Encryption System

Figure 1. Typical Red site configuration.



[1]Simulation Stream II Encapsulated Protocol

Figure 2. . Typical Black site configuration.

2.2.3 DSI Configuration

Two transatlantic links were available for STOW–E. The unencrypted data was routed over a T1 capacity, Ramstein, GE, to Cambridge, MA, link, and the encrypted data was routed over an E1 capacity circuit that ran from the SEAF in Grafenwoehr, GE, to Norfolk, VA. DSI bandwidth was allocated by site. The bandwidth allocations were defined as packets per second (pps) and packet size in bytes. The STOW–E allocations are listed in tables 1 and 2.

Table 1. Red stream sizes for STOW–E.

Site	Rate (pps)	Pkt Size (bytes)
IDA	5	450
Dahlgren	12	450
Newport	12	450
SEAF	25	1000
Cherry Pt	10	1000
BFTT	18	1000
Pax	15	1000
WISSARD	25	1000
TACCSF	30	1000

Table 2. Black stream sizes for STOW–E.

Site	Rate (pps)	Pkt Size (bytes)
SIMNET	220	1000
Rucker	75	1000

2.3 SUMMARY OF THE DATA COLLECTED

Table 2-3 summarizes the data collected during STOW–E. All data were assembled at NRaD.

Table 3. Data collected.

Data	Location	Method	Amount (GB)
All DIS data on the simulation LAN, pre-AG processing	Al Red and Black sites directly connected to DSI (except Dahlgren and Dam Neck)	NRaD DIS Data Logger	24.4
All DIS data, including the AG control PDUs, post-AG processing	Both Black sites SIMNET (Grafenwoehr) and Ft. Rucker, AL	NRaD AG WANLogger	1.0
Statistics: Total loads, number of pkts, number of errors, number of discards, etc.	The E-3 STEP and Sim STEP boards (T/20), and other points in the DSI network	BBN's ANM Software	0.2

3. ANALYSIS PROCESS AND TOOLS

3.1 THE PROCESS

Upon receipt of the STOW–E Dlogger tapes, the STOW–E Test Plan data analysis requirements were fulfilled. The STOW–E Test Plan had the following three general data analysis requirements:

1. Assess the overall performance of the Application Gateway, by site
2. Characterize the DIS traffic generated by each site
3. Estimate the traffic delay and loss across the network

This analysis was completed quickly, but was insufficient. Particularly, the summarization of DIS traffic generated by site was too broad to predict loads for future exercises. A more detailed breakdown was required. Given this evaluation, the data analysis work was transformed into an iterative process of question formulation, determination of whether the answer to the question could be obtained from the data collected, creation or modification of software to extract the desired results, and finally, examination of the results. Once the final analysis requirements had been determined, data samples from all 4 days of STOW–E were processed and integrated.

3.2 THE DATA PROCESSING TOOLS REQUIRED

Software for sorting, filtering, and summarizing the log files was required. The Protocol Data Unit (PDU) Traffic Analyzer (PTA) is a utility developed by ETA Technologies/Advanced Telecommunications, Inc. (ETA/ATI) that can produce a variety of analysis reports or a filtered log file. PTA output files are designed to be uploaded into a spreadsheet for analysis. The PTA was used extensively to filter log files by site, kind, and domain to produce files that detailed load summaries by time interval. These summaries included the number of active entities, the number of each type of PDU observed, and the total number of bits logged. The PTA was designed to analyze Dlogger files, but was modified to process WANLogger files also. Additional WANLogger processing capabilities included the unbundling of packets and identification of compressed PDUs, as well as the tabulation of AG-to-AG control PDUs.

NRaD also developed a set of tools for extracting information from the Dlogger files. The logGrabber extracts a particular time interval from Dlogger files. The logTweaker parses through the PDUs of a log file, displaying a wide range of statistics. Depending on the mode selected, the logTweaker will provide various output formats, some intended for input into other parsing routines.

The logDiff utility was developed to prepare files so that network delays could be estimated. The logDiff operates on log files which were recorded during the same time period at different sites. Having matched every PDU in the first designated file with the PDU's counterpart in the other log files, logDiff can generate a list of "PDU's timestamp delays." This provided the means to track an individual PDU through various log-points to show latency through the network.

3.3 THE DATA SAMPLED

The STOW–E demonstration was executed on 4–7 November 1994. Two-hour time periods from each of the 4 days were sampled. For the Black sites, the time period from 0800–1000 Greenwich Mean Time (GMT) was investigated; for the Red sites, 1100–1300 GMT was selected. Samples across all days were chosen in an attempt to cover the span of STOW–E scenarios. The time period 0800–1000 GMT was a period of heavy activity for the Black sites. The time period 1100–1300 GMT was a period of overlap for Red and Black site activity.

4. THE RESULTS AND DISCUSSION

4.1 APPLICATION GATEWAY

4.1.1 Algorithms

The complete suite of seven AG algorithms were operating throughout STOW–E. These seven algorithms were PDU Culling, Broadcast Grid Filtering, Quiescent Entity Determination (QED), Protocol Independent Compression Algorithm (PICA), Bundling, Overload Management, and LAN Filtering.

4.1.1.1 PDU Culling. PDU Culling discards all non-DIS PDUs as well as ESPDUs that are not within the playbox boundaries. PDU Culling drops all local collision traffic, i.e., collision PDUs in which the Issuing Entity ID Site matches the Colliding Entity ID Site. PDU Culling routes qualifying ESPDUs to the Grid Filtering Algorithm for further processing.

4.1.1.2 Grid Filtering. A playbox area for a current exercise is determined upon startup of the AG. The playbox is divided into squares representing grids that can be referenced by row and column. The width of the grid square is determined at startup with a minimum size of 3 kilometers. Each AG will broadcast Grid Subscribe PDUs to indicate Grids of Interest (GOI) based on the union of the Regions of Interest (ROI) of locally generated entities. A Comprehensive Union (CU) of GOIs is calculated in the Grid Subscription Processor. PDUs that pass the initial PDU Culling analysis as Entity State PDUs will be assigned a grid location based on their coordinates. If the grid location is in the Comprehensive Union, the PDU will be processed as an ESPDU. If the assigned grid location is not in the CU, the PDU will be marked as a Summary Entity (SE) for further processing.

4.1.1.3 Quiescent Entity Determination. QED is responsible for determining if an entity is inactive. All ESPDUs and PDUs marked as Summary Entities that are received from the Grid Filtering Algorithm will be processed by the Quiescent Entity Determination. The QED will compare the most recent ESPDU with the last ESPDU saved in a hash table. If there has been no change in the location, orientation, appearance, or articulated parts, the entity is quiescent. AGs will generate ESPDUs for quiescent entities locally, eliminating the need to repeatedly broadcast unchanging information over the WAN.

4.1.1.4 Compression (PICA). The Protocol Independent Compression Algorithm (PICA) is a differential, no-loss, protocol-independent compression technique that can significantly reduce bit transmission rates in DIS applications. PICA is applied only to ESPDUs in the current AGs. These PDUs, upon first receipt, are saved locally as reference PDUs in the AGs. Subsequent changes to an entity's position or appearance are sent over the network in an abbreviated form as changes to the reference-PDU bit pattern only. The resultant savings in bandwidth usage is the difference in size between complete ESPDUs and these smaller, modifying messages sent in their place.

4.1.1.5 Bundling. The AG Bundling algorithm collects PDUs and concatenates them into larger packets. Bundled packets are transmitted when full (in STOW–E = 1000 bytes) or the preset time-out period (in STOW–E = 40 ms) is reached.

4.1.1.6 Overload Management. The Overload Management algorithm prevents bottlenecks in the traffic flow by dispersing, over time, the transmission of packets from an overloaded site (as opposed to losing them) and, if that action is insufficient, by intelligently discarding packets according to their priority. The Overload Management algorithm determines the most packets per second that should

be allowed for transmission from the AG. AG bandwidth percentages are dynamic after startup to accommodate changing data flow patterns.

4.1.1.7 LAN Filter. The LAN Filter is the only BRT that operates on incoming LAN-bound traffic. A Local Union (LU) of GOIs is computed by the Grid Filtering function using the radar ranges of the local simulation entities. This LU will be used to filter LAN-bound ESPDUs and Summary Entity PDUs. If the grid coordinates of an ESPDU are in the LU, the ESPDU will be transmitted to the LAN. The LAN filter can also eliminate unnecessary ESPDU data from the LAN-bound streams by employing an entity filter; for example, to filter all subsurface entities. All non-ESPDU DIS traffic will be transmitted to the LAN without being filtered, as the potential reduction in traffic does not warrant the processing cost.

4.1.2 Definitions of the Measures of Performance

The AG traffic reduction factor achieved is defined as the ratio of the DIS traffic load generated by the simulations on an individual LAN to the post-AG DIS traffic load offered to the WAN. The loads are DIS payloads only; all Ethernet, User Data Protocol (UDP), Internet Protocol (IP), Stream Protocol (ST) and Improved Network Encryption System (INES) headers have been removed. The LAN traffic includes traffic generated by backdoor sites. The ratio is computed with load measured in both kilobits per second (Kbps) and packets per second (pps).

$$\text{RF(Kbps)} = \frac{\text{Total DIS load generated on the LAN (Kbps)}}{\text{Total DIS load offered to the WAN (Kbps)}}$$

$$\text{RF(pps)} = \frac{\text{Total DIS load generated on the LAN (pps)}}{\text{Total DIS load offered to the WAN (pps)}}$$

For all sites, the LAN loads were calculated from the Dlogger files. For the Red sites, the WAN loads were calculated from Advanced Network Monitor (ANM) data; for the Black sites, WAN loads were calculated from the WANLogger data. Since the Dlogger and WANLogger or ANM monitoring clocks were not synchronized, timing became a confounding issue. All AG performance results in this report assume that the pre-AG and post-AG clocks are in synchronization. The plots of LAN and WAN loads appear to generally support this assumption. Given this constraint, the AG performance measure available provides an overall, longer range description of AG performance. Five-minute, sliding-window averages were used in the calculation of both the LAN and WAN values used in the reduction factor ratios.

4.1.3 Reduction Factor by AG Site

The RF(Kbps) ratio measures the effectiveness of BRT bit reduction. The RF(pps) ratio measures the packet reduction. The BRTs cannot be cleanly divided into those that reduce bits and those that reduce packets. PDU Culling, Grid Filtering, QED, and Overload Management eliminate whole packets from the WAN load. This reduces both the number of bits and the number of packets that the WAN must accommodate. PICA reduces the number of bits that must be transmitted. Without Bundling, PICA would not reduce the number of packets; however, Compression enhances the effect of Bundling when both algorithms are operational, thus reducing the number of packets. Bundling reduces the number of packets, and, though headers have not been included in these ratios, reduces the number of WAN header bits.

All seven BRT algorithms were engaged throughout STOW–E. The STOW–E operational requirements did not allow the investigation of individual BRT performances. Time constraints did

not permit pre-STOW–E BRT benchmarking. Thus, the data available describes the composite performance of the seven BRTs.

4.1.4 Overall AG Performance

Pre-STOW–E analysis indicated that the AG had to provide a four-fold bit reduction to enable STOW–E to be conducted. Post-exercise analysis showed that the real requirement was closer to a three-fold reduction. In fact, the median AG bit reduction was 5.5. The simple mean is 5.9, and the mean weighted by LAN load is 10.6

The reduction of the traffic generated in Germany was critical to achieving success in STOW–E. Though there were occasional overruns of the established stream size at the SEAF, generally, it was not a problem to fit the traffic into the 200 Kbps allocation there. The highest sustained load offered to the Red side was 800 Kbps, so a RF(Kbps) greater than 4 was achieved. The highest sustained load offered to the Black AG system was approximately 700 Kbps. The Black transatlantic link was not stressed. In the U.S., the WISSARD site experienced some overruns. A larger allocation to WISSARD would have remedied this problem.

4.1.5 Results by AG Site

Table 4-1 reports the median Reduction Factors (RF) and the LAN and WAN loads for each AG site. Each value in the table is the median of the four medians calculated for the sites from the 4–7 November 1994 samples. The median is presented because it is a robust estimator of central tendency. The table lists the sites in order of increasing RF(Kbps).

Table 4. Median reduction factors by site.

Sites	LAN Load (pps)	LAN Load (Kbps)	WAN Load (pps)	WAN Load (Kbps)	RF (pps)	RF (Kbps)
NAWC–AD	3.7	4.3	3.3	8.6	1.1	0.5
WISSARD	88.9	106.8	2.9	66.8	30.5	1.6
TACTS	0.6	0.7	2.8	0.4	0.2	1.9
TACCSF	48.1	57.5	3.5	20.5	13.9	2.8
NUWC	4.8	5.5	3.0	0.7	1.6	8.1
AVTB	6.9	8.7	0.1	1.1	54.8	8.1
SEAF	263.7	310.5	3.1	29.6	83.8	10.5
SIMNET	347.9	508.6	4.9	37.7	71.3	13.5

The daily reduction factors are reported in appendix A. The statistics tabulated include the mean, the median, the minimum, and the maximum values. Each table also contains two supporting statistics, the observed minutes, and the mean LAN load for that time sample. Observed minutes is the number of (sliding-window) observations on which the reduction factor calculation was based.

NAWC-AD had a small reduction in packets from the LAN to the WAN. However, in Kbps, the WAN load was heavier than the LAN load. In the case of STOW–E, the only WAN traffic not appearing on the LAN was AG-to-AG control traffic. The NAWC-AD's light LAN load was roughly equaled, in bits, by AG-to-AG control traffic. A heavy AG control load is plausible as the dynamic air traffic simulated by this site could have generated significant changes in grids of interest, AG control traffic.

At WISSARD, the reduction factor in bits was small, but in packets was large. WISSARD's heavy air traffic was not a good candidate for bit reduction, but the effect of bundling was marked. Note that six uncompressed ESPDUs (zero articulated parts = 144 bytes) can be bundled in a 1000-byte packet.

TACTS had about the same RF(Kbps) as WISSARD, but had an RF(Kbps) less than one. As a WISSARD, bit reduction at TACTS was only marginally reduced by the AG algorithms. However, unlike WISSARD, TACTS generated a very light LAN load, so bundling did not have an effect. In fact, due to AG-to-AG control traffic, there were more packets on the WAN than the LAN.

Among the Red sites, TACCSF generated the second largest LAN load. More bit reduction was observed here than at WISSARD, which had the highest Red LAN load. Note that WISSARD generated almost exclusively air entities, whereas TACCSF had a very large number of land platforms.

At NUWC, a minimal RF(Kbps) on a light LAN load is again observed. A large RF(Kbps) was observed at AVTB. This is surprising considering the relatively small LAN load. Traffic generation at AVTB must have been very sporadic.

The SIMNET (Black) and SEAF (Red) sites transmitted approximately the same traffic. Both transmitted the SIMNET virtual simulation load generated in Grafenwoehr and the BBS and CMTC-IS loads from Hohenfels, GE. In addition, the SEAF transmitted the Ft. Rucker (Black data) onto the Red DSI network and the traffic from RAF Lakenheath and the Falcon Star simulator. The SIMNET site has a higher median LAN load in table 4-1 because the Red and Black sites were sampled at different times. Typically, the heaviest Black loads were generated from 0800–1100 GMT. SIMNET, BBS, and CMTC-IS activity continued after the Red sites joined the demonstration, but at a lower level.

The largest RF(pps) and RF(Kbps) were observed at the SEAF and SIMNET. There are a number of easily identifiable reasons for this. Forty percent of the BBS traffic consisted of experimental Aggregate and Mine Marker PDUs. All of those PDUs were culled. The median value of ESPDUs/s/entity for BBS land, air, and dismounted infantry entities was 0.2. This suggests significant "heartbeat" output by BBS. (Heartbeat traffic is quiescent, so it is handled locally by the QED algorithms rather than output to the WAN). There were problems with at least some of the DIS traffic output by CMTC-IS. Static time stamps and ESPDUs with all zeros were observed. Such LAN traffic would result in minimal traffic to the WAN.

The presence of AGWANLoggers at AVTB and SIMNET allowed the AG reduction factors for the various entity kind/domain pairs to be estimated separately. Table 4-2 shows the median results. Appendix D contains more complete summary information.

4.1.6 AG Control Load and Packets/Bundle

The following three measures describe the AG bundling BRT and AG control loads: DIS packets/AG bundle, AG control load (Kbps), and percent of total WAN load attributable to AG control traffic. The AG was bundling DIS packets into 1000-byte packets with a maximum time-to-fill equal to 40 milliseconds (ms). The following statistics were calculated from SIMNET and Rucker WANLogger files that cover the 0800–1000 GMT sample period. All of the traffic on the WAN was included, not just the locally generated traffic; thus, if the WANLogger samples covered exactly the same time periods and if there was no loss over the DSI, the statistics at Rucker and SIMNET would be the same. All of the SIMNET/Rucker statistic pairs are roughly equal, so the following statistics are considered reliable.

Table 5. AG median reduction factors at Black sites.

	AG Reduction Factor (pps)	AG Reduction Factor (Kbps)
PLATFORMS (kind=1)		
Land (Domain=1)		
Live		
CMTC	4700	600
Virtual		
SIMNET	36	6.2
Constructive		
BBS	38	6.3
Rucker	19	3.4
Air (Domain=2)		
Live		
CMTC	500	60
Virtual		
SIMNET	313	45
Falcon Star	9.7	1.4
Rucker	100	13.9
Constructive		
BBS	36	10.8
LIFE FORM (kind=3)		
Land (Domain=1)		
Live	1700	240
CMTC		
Virtual		
SIMNET	16	2.8
Constructive		
BBS	83	12.1

The number of DIS packets/AG bundle for 4, 6, and 7 November 1994 all cluster around 15. The number of DIS packets/bundle for 5 November 1994 is approximately seven. The number of full size ESPDUs/1000 byte bundle is approximately seven. It is possible that on 5 November, bundling accidentally had different parameters. It is also possible that on this date, PICA was not on, so ESPDUs were not being compressed as on the other days. The median AG control load was 0.16 Kbps, accounting for 0.40 % of the total WAN load. The measures are summarized in table 4-3. The last table of appendix A contains these measures for each site for each day.

Table 6. AG performance.

Measure	Median	Mean
DIS packets/bundle 4, 6, 7 November 1994 5 November 1994	 14.80 7.10	 15.00 7.10
AG Control load (Kbps)	0.16	0.31
% of total load that is AG control traffic	0.40	0.67

4.2 CHARACTERIZATION OF NETWORK TRAFFIC

4.2.1 Entity Types

The breakdown of entity types actually generated in STOW–E was very close to that predicted in May 1994. The May 1994 predictions and the actual breakdown on 6 November 1994 are listed in table 4-4.

Table 7. Predicted and actual STOW–E entity types.

Type	Predicted (%)	Actual (%)
Land entities	86.6	90.4
Air entities	12.0	8.1
Ship	1.2	1.3
Submarine	0.2	0.2

Tables presenting the entities simulated in each of the time samples are contained in appendix B. For each site, the number of entities in the kind/domain pairs listed in table 4-5 is recorded. (Note that this is not an exhaustive list of all kind/domain pairs allowed by the DIS standard. It should also be noted that some simulations generated data with invalid kind and domain values.)

Table 8. Number of entities in kind/domain pairs.

Kind	Domain
Platform (1)	Land (1) Air (2) Surface (3) Subsurface (4)
Munition (2)	Anti-Air (1) Anti-Armor (2)
Life form (3)	

4.2.2 PDU Percentages

In STOW–E, only 81% of the packet load was due to ESPDU. Prior to STOW–E, it was estimated that over 90% of the PDUs generated would be ESPDUs. The discrepancy is due to the heavy experimental PDU load generated by BBS.

Appendix C contains tables with the percentages of Entity State, Fire, Detonation, Collision, and Experimental PDUs. Excluding the Experimental PDUs, the following breakdown of PDU types

was observed: ESPDUs: 99.8%; Fire PDUs: 0.1%; and Detonation PDUs: 0.1%. No collision PDUs were observed in these samples. The BBS in Hohenfels, GE, was the only simulation that generated experimental PDUs. BBS generated Mine Marker and Aggregate Experimental PDUs. These Experimental PDUs accounted for approximately 40% of the BBS traffic.

4.2.3 Loads Generated by Entities

The traffic loads expected to be generated by the various entity types is critical information for exercise planning. So, in addition to calculating LAN loads by site, estimates were made of the traffic generated by land, air, surface, and subsurface platforms. A very broad range of loads for land and air platforms was found. The munitions and life form kinds were separated from the platforms, but the range of traffic loads was still high. Finally, estimates were broken down further by simulation type and physical site (not just AG site).

The traffic loads generated, expressed by ESPDU/s/entity, is tabulated in the Overall Summary spreadsheet in appendix D. The table includes the 25th percentile of the ESPDU/s/entity distribution, the median value, and the 75th percentile of the distribution. The Overall Summary is the composite of daily traffic loads generated from 4–7 November 1994. In the Overall Summary, the 25th percentile is the lowest of the 25th percentile of the three days, the 50th percentile is the middle value, and the 75th percentile is the highest of the three percentiles calculated.

It is important to understand what the values in this spreadsheet represent. The numbers describe the distribution of load generated over all entities. This is not the distribution observed for a single entity. This does not say that when a land entity is in a low activity state (25th percentile), it has an ESPDU/s/entity generation rate of 0.1 or that when it is in a high activity state (75th percentile), it has a rate of 1.1 ESPDU/s/entity. These figures are merely averages used in estimating the offered load of a specific set of entities.

The "peakiness" of network traffic is an important issue in sizing networks. The calculations used to calculate the values discussed so far have smoothed the data over 1-minute intervals. Additional information on the effects of this "peakiness" has been published by Bolt, Beranek, and Newman, Inc. (1995).

4.2.4 Prediction Worksheet

Table 4-6 contains entity data for two sets of entity data generation rates. The rates obtained from the Communication Architecture for the DIS (CADIS) document and the Firestarter exercise exercise were used to estimate STOW–E bandwidth requirements prior to the exercise. These estimates assume that 93% of the packets and 97% of the bits are due to ESPDUs. With these estimates, the STOW–E Black load was predicted to be 2122 Kbps, and the Red load was predicted to be 878 Kbps. The second set of rates are based on the 75th percentiles of the generation rates actually observed in STOW–E. In STOW–E, 87% of the packets and 71% of the bit load were due to ESPDUs. With these values, the predicted Black load is 2036 Kbps, and the predicted Red load is 596 Kbps. Table 4-7 summarizes the STOW–E predictions and actual loads observed.

Appendix E contains a spreadsheet with the original STOW–E predictions and a second spreadsheet with the update predictions.

4.3 NETWORK DELAYS

4.3.1 Delay Analysis Overview

The task of reporting network delays for STOW–E entailed tracking PDUs through the network and reporting time differences (usually reported at a resolution of 1/100th of a second) between log

Table 9. Entity data generation rates.

	Based on CADIS/Firestarter		Based on STOW–E	
Sites	Rate (pps)	Rate (Kbps)	Rate (pps)	Rate (Kbps)
Submarine	0.22	0.32	0.62	1.09
Ship	1.08	2.13	0.49	1.16
Fixed-Wing Aircraft	4.22	6.27	2.10	3.72
Rotary-Wing Aircraft	2.15	3.20	1.36	2.40
Tank	0.75	1.30	0.62	1.27
Truck	0.75	1.12	0.62	1.09
Dismounted Infantry	0.75	1.12	0.62	1.09

Table 10. STOW–E predictions and loads.

Actual Load (Kbps)	Original Prediction (Kbps)	Update Prediction (Kbps)
Black: 680	2122	2036
Red: 212	878	596

points. This procedure, in itself, requires sophisticated tools to match PDUs in multiple log files. However, once a PDU has been successfully matched in two log files, it is trivial to calculate the difference between the time stamps of the PDUs to reveal the network delay between those two log points. This procedure assumes, of course, that the time stamping mechanisms in the loggers are synchronized.

4.3.2 Clock Synchronization

An added level of complexity was introduced into the delay analysis by the fact that the time-of-day clocks on all the data collection devices were not synchronized. A plan to use GPS time servers at Kirtland, Newport, Pax, WISSARD, SEAF, and Rucker was not fully implemented due to schedule constraints. Since the data loggers were not time stamping from the same clock source, a time stamp correction method was needed.

As no Black sites had GPS time synchronization, clock offset correction was performed for the PDUs passed between Ft. Rucker and SIMNET. On the Red side, Pax River, Newport, and Kirtland each had a local GPS time server, so delay information was calculated between these sites with no time correction performed.

An algorithm used by the Network Time Protocol (NTP) was used to estimate clock offsets (Mills, 1991). To arrive at an estimated clock offset between two log points, this method requires raw delay data between the two locations. The algorithm then provides round-trip packet delay (equal delay in both directions), and an estimated clock offset. It should be noted that the system clocks in the logging machines at SIMNET were both set approximately one hour fast. This fact was a major obstacle when trying to correlate delay information with traffic loads and exercise events.

4.3.3 Time Intervals

Given the quantity of data available and the intensive calculations required for the PDU delay analysis, delay information is reported for specific, representative time intervals only. For the Black

sites (Ft. Rucker and SIMNET), times between 0800 Greenwich Mean Time (GMT) and 1000 GMT were selected for 4–6 November. For the Red sites, delay data was investigated among Newport, Pax River, and Kirtland for 1100–1300 GMT on 6 November.

4.3.4 Delay Results

The WANLoggers at Ft. Rucker and SIMNET allowed the end-to-end delay to be split into three components: the delay through the Ft. Rucker AG, the delay across the DSI, and the delay through the SIMNET AG. Based on the estimates from both Ft. Rucker and SIMNET, the mean delay through the AG was 0.52 s. The delay across the DSI was 0.15 s.

As the Red sites did not have WANLoggers, the components of the end-to-end delay could not be separated. Based on delay estimates among three GPS time-synchronized sites, a mean end-to-end delay of 3.12 s was observed. A discussion of the observed delays follows. Detailed results are provided in appendix F.

4.3.4.1 Black Site PDU Transfer Delays. The first table in appendix F shows the mean delay through the AG at Ft. Rucker (Rucker AG), the mean delay across the DSI, and the corresponding mean delay through the AG at the SIMNET (SIMNET AG) facility, for each of the four time intervals. The four accompanying figures illustrate the component delays at each of the log points through the network. A table corresponding to each figure shows a breakdown of PDU counts and LAN and WAN loads.

With the exception of 4 November, the delays across the Rucker AG are relatively consistent. A mean delay of 1.03 s through Rucker AG can perhaps be explained by the heavy load on the SIMNET LAN on 4 November. A large number of entities from SIMNET could conceivably have taken up Rucker AG processor bandwidth with increased unbundling/processing requirements from the Ft. Rucker-bound PDUs.

Delays across the DSI were consistently on the order of 100–200 ms. For a transatlantic hop, these numbers are reasonable.

For three of the four Black time intervals, SIMNET AG mean PDU delays were around 200 ms. From 09:12–09:26 GMT on 6 November, the delay through SIMNET AG was 1.51 s. The SIMNET LAN had a load of 431 DIS packets/s The SIMNET AG was required to examine and make complex decisions on whether and how to pass these packets on to the DSI WAN. Depending on the scenario and how many entities were processed for WAN transmission, the SIMNET AG could have been overloaded. Any extra processing performed by the AG_{SIMNET} could potentially have increased the PDU latency.

4.3.4.2 Red Site PDU Transfer Delays. There were no loggers on the WAN side of the AGs for the Red sites. This means that only end-to-end delays could be reported. Additionally, to avoid the error-inducing calculations involved with correcting unsynchronized clocks, only sites that had a local GPS time server on their LAN were included in the Red site delay report. Since three sites (Newport, Pax River, and Kirtland) had GPS time servers, a representative sample of delays was assumed.

The last entry in appendix F is a table that displays round-trip PDU delays between Newport, Pax River, and Kirtland for 1100–1300 GMT on 6 November. These delays include two AG-processing delays plus the propagation delay across the DSI. The enormous maximum delays are possibly due

to a shortcoming in the PDU-matching tool. If a simulator puts out duplicate PDUs, the PDU-matching function can be fooled since there is no way to differentiate duplicate PDUs. It is assumed, on the basis of the mean and median delays, that the extremely high maximums are anomalous. This mismatching of PDUs also explains the slightly negative minimums.

4.3.5 PDUs Dropped by the Network

An important function of the AG was to reduce the offered PDU network traffic to the WAN by intelligently dropping packets when required. As a result, it only makes sense to try to detect missing or dropped PDUs between the WAN sides of the AGs. The Red side had no WAN loggers, so dropped PDUs could not be determined for the Red traffic.

Dropped-PDU analysis for the Black sites (Ft. Rucker and SIMNET) was performed for the same time intervals as for the PDU delay investigations. The method was to determine a set of PDUs generated at a particular site, and then to find/match the corresponding PDUs in the WAN-side log files at the other site.

The result of this analysis was that all Ft. Rucker-generated PDUs detected in the Ft. Rucker WAN log file were also found in the SIMNET WAN log file. Likewise, all SIMNET-generated PDUs detected in the SIMNET WAN log file were matched in the Ft. Rucker WAN log file. So, for the time periods examined, there were no dropped PDUs over the Black side DSI.

5. LESSONS LEARNED

Eight principle lessons were learned during STOW–E and the subsequent data analysis period. All indicate steps that should be taken in the future to help the post-exercise processing and analysis of performance data. (It should be noted that some of these actions were planned for STOW–E, but could not be implemented due to time or monetary constraints.)

1. More detailed instrumentation of the network, especially the Application Gateway, would provide more useful statistics.
2. Summary end-of-the-day and end-of-the-demonstration performance statistics should be automatically generated. These statistics could be generated from a combination of real-time monitoring history files and datalogger files.
3. Measures of performance that are known to be of interest need to be precisely defined as early as possible.
4. All sites require synchronized clocks.
5. Datalogging should be automated to log all data. This could imply that all sites run loggers 24 hours a day.
6. Expected use of Experimental PDUs must be determined ahead of time and included in bandwidth-demand estimates.
7. Verification of the DIS-compliance of all participating simulations would improve network troubleshooting.
8. A record of the military scenario, for correlation with network performance, would be valuable.

6. CONCLUSIONS

The primary conclusion is that the AG was indispensable in making STOW–E a success. The network could not have accommodated the unreduced traffic loads generated by the participating simulations without it. Highlights of the AG's performance include the following:

a. The overall median AG reduction factor in Kbps was 5.5 times.

b. The reduction factor at the critical SEAF (Red), Grafenwoehr, GE, site was 10.5 times.

The DIS loads generated in STOW–E were highly simulation-specific, and often, highly variable within a simulation. Tight predictions of loads expected in future exercises requires much more work.

The large network delays observed were unexpected. Explanations for these delays were not apparent. From the users' point of view, however, network delays were not an issue in STOW–E. No packet loss was observed over the network.

A new architecture must be developed to support still larger DIS exercises. The primary concerns are to reduce the processing load on the AG host and to make use of new network services (e.g., multicasting) to reduce the delivery of unnecessary traffic on both the WAN and the LAN.

7. REFERENCES

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8. ACRONYMS

AG	Application Gateway
ANM	Advanced Network Monitor
AVTB	Aviation Testbed
BBS	Battalion/Brigade Battle Simulation
BFTT	Battle Force Tactical Trainer
BRT	Bandwidth–Demand Reduction Technique
CMTC–IS	Combat Maneuver Training Center–Instrument System
CU	Comprehensive Union
DIS	Distributed Interactive Simulation
Dlogger	Data Logger
DoD	Department of Defense
DSI	Defense Simulation Internet
ESPDU	Entity State Protocol Data Unit
GOI	Grids of Interest
GPS	Global Positioning System
GMT	Greenwich Mean Time
IDA	Institute for Defense Analyses
INES	Improved Network Encryption System
IP	Internet Protocol
Kbps	Kilobits Per Second
LAN	Local Area Network
LU	Local Union
Mbps	Mega bits per second
NAWC–AD	Naval Air Weapons Center Aircraft Division
NES	Network Encryption System
NRaD	Naval Command Control and Ocean Surveillance Center, Research, Development, Test and Evaluation Division
NSWC	Naval System Warfare Center
NUWC	Naval Undersea Weapons Center
PDU	Protocol Data Unit
PTA	PDU Traffic Analyzer
PICA	Protocol Independent Compression Algorithm
pps	Packets per seconds
QED	Quiescent Engity Determination
RAF	Royal Air Force
ROI	Regions of Interest

SE	Summary Entity
SEAF	STOW–E Engineering and Analysis Facility
SIMNET	Simulation Network
ST	Stream Protocol
STEP	Stream II Encapsulated Protocol
STOW–E	Synthetic Theater of War–Europe
TACCSF	Tactical Air Combat Training System Facility
TACTS	Tactical Aircrew Combat Training System
TBA	Theater Battle Arena
UDP	User Data Protocol
USAF	United States Air Force
WAN	Wide Area Network
WANLogger	Wide Area Network Logger
WISSARD	What If Simulation Systems for Research and Development
WPS	Wideband Packet Switch

APPENDIX A
AG PERFORMANCE

Table A-1. AG performance at unencrypted sites: LAN load (Kbps)/WAN load (Kbps), 11/4/94, 0800–1000 GMT.

	Reduction Ratio (Kbps)					Mean LAN Load (Kbps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
SIMNET, Grafenwoehr, GE	15.4	13.4	8.3	37.1	117.0	514.0
AVTB, Ft. Rucker, AL	9.2	8.8	0.9	14.3	116.0	9.2

Table A-2. AG performance at unencrypted sites: LAN load (pps)/WAN load (pps), 11/4/94, 0800–1000 GMT.

	Reduction Ratio (pps)					Mean LAN Load (pps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
SIMNET, Grafenwoehr, GE	75.0	57.0	36.9	217.6	117.0	287.0
AVTB, Ft. Rucker, AL	62.0	59.0	5.9	97.3	116.0	7.0

Table A-3. AG performance at unencrypted sites: LAN load (Kbps)/WAN load (Kbps), 11/5/94, 0800–1000 GMT.

	Reduction Ratio (Kbps)					Mean LAN Load (Kbps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
SIMNET, Grafenwoehr, GE	16.6	16.6	10.8	21.3	118.0	446.0
AVTB, Ft. Rucker, AL	8.9	7.3	1.3	19.2	73.0	8.1

Table A-4. AG performance at unencrypted sites: LAN load (pps)/WAN load (pps), 11/5/94, 0800–1000 GMT.

	Reduction Ratio (pps)					Mean LAN Load (pps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
SIMNET, Grafenwoehr, GE	81.3	82.7	48.3	105.1	118.0	273.0
AVTB, Ft. Rucker, AL	63.3	50.6	9.9	166.8	73.0	6.8

Table A-5. AG performance at unencrypted sites: LAN load (Kbps)/WAN load (Kbps), 11/6/94, 0800–1000 GMT.

	Reduction Ratio (Kbps)					Mean LAN Load (Kbps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
SIMNET, Grafenwoehr, GE	13.4	13.5	9	17.6	69	671.2
AVTB, Ft. Rucker, AL	Insufficient WAN data					

Table A-6. AG performance at unencrypted sites: LAN load (pps)/WAN load (pps), 11/6/94, 0800–1000 GMT.

	Reduction Ratio (pps)					Mean LAN Load (pps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
SIMNET, Grafenwoehr, GE	72	72.6	52	92.6	69	449.2
AVTB, Ft. Rucker, AL	Insufficient WAN data					

Table A-7. AG performance at unencrypted sites: LAN load (Kbps)/WAN load (Kbps), 11/7/94, 0800–1000 GMT.

	Reduction Ratio (Kbps)					Mean LAN Load (Kbps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
SIMNET, Grafenwoehr, GE	10.8	10.5	7.4	14.7	116	503.1
AVTB, Ft. Rucker, AL	No WAN data available					

Table A-8. AG performance at unencrypted sites: LAN load (pps)/WAN load (pps), 11/7/94, 0800–1000 GMT.

	Reduction Ratio (pps)					Mean LAN Load (pps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
SIMNET, Grafenwoehr, GE	70.0	69.9	48.2	95.6	116	408.7
AVTB, Ft. Rucker, AL	No WAN data available					

Table A-9. AG performance: packets/bundle.

DIS pkts/bundle						
AG	**Date**	**Mean**	**Median**	**Min**	**Max**	**Num Min.**
SIMNET	11/4/94	14.8	14.8	11.6	17.7	325
SIMNET	11/5/94	7.0	7.0	5.5	7.9	316
SIMNET	11/6/94	15.5	15.4	6.9	18.8	366
SIMNET	11/7/94	14.8	14.6	5.5	13.1	159
Rucker	11/4/94	14.6	14.7	11.5	15.9	222
Rucker	11/5/94	7.1	7.1	6.2	7.9	106
Rucker	11/6/94	15.2	15.3	13.8	16.2	195
Rucker	11/7/94	No data				

Table A-10. AG control load (Kbps).

AG	Date	Mean	Median	Min	Max	Num Min.
SIMNET	11/4/94	0.29	0.14	0.00	22.4	325
SIMNET	11/5/94	0.18	0.14	0.01	2.9	316
SIMNET	11/6/94	0.4	0.20	0.00	9.6	442
SIMNET	11/7/94	0.24	0.17	0.04	2.0	159
Rucker	11/4/94	0.23	0.14	0.01	1.1	222
Rucker	11/5/94	0.21	0.16	0.00	2.2	106
Rucker	11/6/94	0.60	0.3	0.02	4.9	195
Rucker	11/7/94	No data				

Table A-11. AG control traffic (% of total load).

AG	Date	Mean	Median	Min	Max	Num Min.
SIMNET	11/4/94	0.72	0.39	0.00	44.90	325
SIMNET	11/5/94	0.40	0.30	0.02	14.00	316
SIMNET	11/6/94	1.10	0.70	0.00	13.30	442
SIMNET	11/7/94	0.40	0.30	0.03	2.50	159
Rucker	11/4/94	0.54	0.30	0.01	7.70	222
Rucker	11/5/94	0.50	0.40	0.00	4.80	106
Rucker	11/6/94	1.00	0.60	0.01	6.40	195
Rucker	11/7/94	No data				

Table A-12. AG performance at encrypted sites: LAN load (Kbps)/WAN load (Kbps), 11/4/94, 1100–1300 GMT.

	Reduction Ratio (Kbps)					Mean LAN Load (Kbps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
BFTT, Dam Neck, VA	Bad Dlogger tape					
IDA, Alexandria, VA	Viewport					
NAWC–AD, Patuzent River, MD	0.3	0.3	0.1	0.7	116	1.6
NSWC–DD, Dahlgren, VA	No Dlogger on site					
NUWC, Newport, RI	12.1	9.0	3.9	67.5	114	1.7
SEAF, Grafenwoehr, GE	6.6	6.1	4.5	14.8	118	262.8
TACCSF, Kirtland AFB, NM	2.7	2.6	2.1	4.7	112	60.9
TACTS, Cherry Point, NC	6.7	2.5	0.6	46.3	49	0.7
WISSARD, NAS Oceana	1.9	1.9	1.4	2.2	116	135.2

Table A-13. AG performance at encrypted sites: LAN load (Kbps)/WAN load (Kbps), 11/5/94, 1100–1300 GMT.

	Reduction Ratio (Kbps)					Mean LAN Load (Kbps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
BFTT, Dam Neck, VA	Bad Dlogger tape					
IDA, Alexandria, VA	Viewport					
NAWC–AD, Patuxent River, MD	1.2	0.4	0.1	29.1	117.0	8.3
NSWC–DD, Dahlgren, VA	No Dlogger on site					
NUWC, Newport, RI	11.9	7.8	4.0	116.9	117.0	6.0
SEAF, Grafenwoehr, GE	3.9	3.8	0.8	7.6	104.0	224.8
TACCSF, Kirtland AFB, NM	3.4	2.8	1.8	6.9	118.0	56.1
TACTS, Cherry Point, NC	3.1	1.7	0.6	20.3	70.0	0.6
WISSARD, NAS Oceana	1.6	1.5	0.6	3.1	116.0	78.4

Table A-14. AG performance at encrypted sites: LAN load (Kbps)/WAN load (Kbps), 11/6/94, 1100–1300 GMT.

	Reduction Ratio (Kbps)					Mean LAN Load (Kbps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
BFTT, Dam Neck, VA	Bad Dlogger tape					
IDA, Alexandria, VA	Viewport					
NAWC–AD, Patuxent River, MD	1.2	1.2	0.4	2.8	116.0	4.1
NSWC–DD, Dahlgren, VA	No Dlogger on site					
NUWC, Newport, RI	5.4	5.1	2.6	11.1	116.0	4.9
SEAF, Grafenwoehr, GE	15.2	14.8	5.6	24.7	116.0	422.5
TACCSF, Kirtland AFB, NM	4.9	4.6	3.5	6.8	104.0	57.5
TACTS, Cherry Point, NC	4.2	2	0.7	31.9	49.0	1.4
WISSARD, NAS Oceana	1.7	1.7	1.1	2.2	117.0	143.7

Table A-15. AG performance at encrypted sites: LAN load (Kbps)/WAN load (Kbps), 11/7/94, 1100–1300 GMT.

	Reduction Ratio (Kbps)					Mean LAN Load (Kbps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
BFTT, Dam Neck, VA	Bad Dlogger tape					
IDA, Alexandria, VA	Viewport					
NAWC–AD, Patuxent River, MD	0.7	0.5	0.2	1.5	117.0	4.4
NSWC–DD, Dahlgren, VA	No Dlogger on site					
NUWC, Newport, RI	7.9	8.4	3.2	12.5	117.0	6.5
SEAF, Grafenwoehr, GE	15.5	15.4	9.0	19.7	81.0	358.2
TACCSF, Kirtland AFB, NM	No data					
TACTS, Cherry Point, NC	3.8	1.0	0.7	48.0	49.0	0.62
WISSARD, NAS Oceana	1.5	1.4	0.9	3.3	117.0	38.5

Table A-16. AG performance at unencrypted sites: LAN load (pps)/WAN load (pps), 11/4/94, 1100–1300 GMT.

	Reduction Ratio (pps)					Mean LAN Load (pps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
BFTT, Dam Neck, VA	Bad Dlogger tape					
IDA, Alexandria, VA	Viewport					
NAWC–AD, Patuxent River, MD	0.4	0.4	0.2	0.8	116.0	1.4
NSWC–DD, Dahlgren, VA	No Dlogger on site					
NUWC, Newport, RI	0.5	0.4	0.2	1.2	114.0	1.5
SEAF, Grafenwoehr, GE	59.1	70.4	2.3	82.5	118.0	217.3
TACCSF, Kirtland AFB, NM	17.6	13.9	7.4	21.3	112.0	52.1
TACTS, Cherry Point, NC	0.2	0.1	0.1	1.0	49.0	0.6
WISSARD, NAS Oceana	38.5	40.0	7.0	53.9	116.0	114.8

Table A-17. AG performance at unencrypted sites: LAN load (pps)/WAN load (pps), 11/5/94, 1100–1300 GMT.

	Reduction Ratio (pps)					Mean LAN Load (pps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
BFTT, Dam Neck, VA	Bad Dlogger tape					
IDA, Alexandria, VA	Viewport					
NAWC–AD, Patuxent River, MD	2.5	1.1	0.3	13.4	117.0	7.2
NSWC–DD, Dahlgren, VA	No Dlogger on site					
NUWC, Newport, RI	1.7	1.9	0.2	2.7	117.0	5.2
SEAF, Grafenwoehr, GE	56.0	70.1	0.5	114.8	104.0	224.8
TACCSF, Kirtland AFB, NM	15.0	14.8	10.8	23.4	118.0	48.1
TACTS, Cherry Point, NC	0.2	0.1	0.0	0.4	68.0	0.5
WISSARD, NAS Oceana	22.8	20.9	1.2	41.7	116.0	63.0

Table A-18. AG performance at unencrypted sites: LAN load (pps)/WAN load (pps), 11/6/94, 1100–1300 GMT.

	Reduction Ratio (pps)					Mean LAN Load (pps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
BFTT, Dam Neck, VA	Bad Dlogger tape					
IDA, Alexandria, VA	Viewport					
NAWC–AD, Patuxent River, MD	1.2	1.2	0.6	1.7	116.0	3.5
NSWC–DD, Dahlgren, VA	No Dlogger on site					
NUWC, Newport, RI	1.4	1.4	0.9	1.9	116.0	4.3
SEAF, Grafenwoehr, GE	97.5	98.0	70.0	122.5	116.0	333.8
TACCSF, Kirtland AFB, NM	14.1	13.9	11.8	17.7	104.0	41.7
TACTS, Cherry Point, NC	0.4	0.3	0.1	0.9	49.0	1.2
WISSARD, NAS Oceana	43.3	44.5	5.2	66.9	117.0	121.0

Table A-19. AG performance at unencrypted sites: LAN load (pps)/WAN load (pps), 11/7/94, 1100–1300 GMT.

	Reduction Ratio (pps)					Mean LAN Load (pps)
Site	Mean	Median	Min.	Max.	Obs. Min.	
BFTT, Dam Neck, VA	Bad Dlogger tape					
IDA, Alexandria, VA	Viewport					
NAWC–AD, Patuxent River, MD	1.3	1.1	0.5	2.3	117.0	3.8
NSWC–DD, Dahlgren, VA	No Dlogger on site					
NUWC, Newport, RI	1.9	1.7	1.3	3.1	117.0	5.6
SEAF, Grafenwoehr, GE	97.5	97.2	61.8	121.0	81.0	302.5
TACCSF, Kirtland AFB, NM	No data					
TACTS, Cherry Point, NC	0.2	0.2	0.1	0.4	49.0	0.5
WISSARD, NAS Oceana	10.2	9.8	2.0	21.8	117.0	29.0

APPENDIX B
DIS TRAFFIC

Table B-1. Numbers of entities, by domain, by kind, at unencrypted sites: 11/4/94 from 0800–1000 GMT.

	Platform (1)					Munition (2)			Life-form (3)	
Site	**Land (1)**	**Air (2)**	**Ship (3)**	**Sub (4)**	**Sub-total**	**Anti-Air (1)**	**Anti-Armor (2)**	**Sub-total**	**Land (1)**	**Total**
SIMNET, Grafenwoehr, GE	74	1	0	0	75	0	0	0	2	77
BBS, Hohenfels, GE	556	8	0	0	564	1	4	5	327	896
CMTC–IS, Hohenfels, GE	420	32	0	0	452	0	0	0	65	517
Falcon Star, Grafenwoehr, GE					0			0		0
AVTB, Ft. Rucker, AL	42	8	0	0	50	0	8	8	1	59
Total	1092	49	0	0	1141	1	12	13	395	1549
Percentages (%)	70.50	3.16	0.00	0.00	73.66	0.06	0.77	0.84	25.50	

Table B-2. Numbers of entities, by domain, by kind, at encrypted sites: 11/4/94 from 1100–1300 GMT.

	Platform (1)					Munition (2)			Life-form (3)	
Site	Land (1)	Air (2)	Ship (3)	Sub (4)	Sub-total	Anti-Air (1)	Anti-Armor (2)	Sub-total	Land (1)	Total
*BFTT, Dam Neck, VA	9	0	31	0	40	0	0	0	0	40
AEGIS ship, Mayport, FL	0	0	1	0	1	0	0	0	0	1
IDA, Alexandria, VA										
*NAWC–AD, Patuxent River, MD	2	38	0	0	40	0	0	0	0	40
USAF Armstrong Lab, Mesa, AZ	0	2	0	0	2	0	0	0	0	2
NSWC–DD, Dahlgren, VA	0	0	1	0	1	0	0	0	0	1
NUWC, Newport, RI	0	0	3	3	6	0	0	0	0	6
SEAF, Grafenwoehr, GE										
SIMNET (routed through Guard)	69	1	0	0	70	0	0	0	2	72
CMTC (routed through Guard)	420	32	0	0	452	0	0	0	65	517
BBS (routed through Guard)	317	6	0	0	323	0	0	0	164	487
Rucker replay (routed through Guard)					0					0
RAF Lakenheath, UK	0	1	0	0	1	0	0	0	0	1
Falcon Star	0	1	0	0	1	0	0	0	0	1
TACCSF, Kirtland AFB, NM	163	19	0	0	182	14	0	14	0	196
TBA, Pentagon, Washington, DC	17	3	0	0	20	0	0	0	0	20
TACTS, Cherry Point, NC	1	1	0	0	2	0	0	0	0	2
WISSARD, NAS Oceania	2	21	0	0	23	32	0	32	0	55
Total	1000	125	36	3	1164	46	0	46	231	1441
Percentages (%)	69.40	8.67	250	0.21	80.78	3.19	0.00	3.19	16.03	

*As recorded at WISSARD.

Table B-3. Numbers of entities, by domain, by kind, at unencrypted sites: 11/5/94 from 0800–1000 GMT.

	Platform (1)					Munition (2)			Life-form (3)	
Site	**Land (1)**	**Air (2)**	**Ship (3)**	**Sub (4)**	**Sub-total**	**Anti-Air (1)**	**Anti-Armor (2)**	**Sub-total**	**Land (1)**	**Total**
SIMNET, Grafenwoehr, GE	60	0	0	0	60	0	0	0	2	62
BBS, Hohenfels, GE	602	12	0	0	614	2	1	3	183	800
CMTC–IS, Hohenfels, GE	429	36	0	0	465	0	0	0	69	534
Falcon Star, Grafenwoehr, GE										
AVTB, Ft. Rucker, AL	0	8	0	0	8	0	15	15	0	23
Total	1091	56	0	0	1147	2	16	18	254	1419
Percentages (%)	76.89	3.95	0.00	0.00	80.83	0.14	1.13	1.27	17.90	

Table B-4. Numbers of entities, by domain, by kind, at encrypted sites: 11/5/94 from 1100–1300 GMT.

	Platform (1)					Munition (2)			Life-form (3)	
Site	Land (1)	Air (2)	Ship (3)	Sub (4)	Sub-total	Anti-Air (1)	Anti-Armor (2)	Sub-total	Land (1)	Total
*BFTT, Dam Neck, VA	10	0	18	0	28	0	0	0	0	28
AEGIS ship, Mayport, FL	0	0	3	0	3	0	0	0	0	3
IDA, Alexandria, VA	Viewport									0
NAWC–AD, Patuxent River, MD	2	45	0	0	47	3	0	0	0	47
USAF Armstrong Lab, Mesa, AZ	0	2	0	0	2	3	0	0	0	2
*NSWC–DD, Dahlgren, VA	0	0	1	0	1	0	0	0	0	1
NUWC, Newport, RI	0	0	4	3	7	0	0	0	0	7
SEAF, Grafenwoehr, GE	0	0	0	0	0	0	0	0	0	0
SIMNET (routed through Guard)	60	0	0	0	60	0	0	0	2	62
CMTC (routed through Guard)	429	36	0	0	465	0	0	0		465
BBS (routed through Guard)	1182	23	0	1	1206	0	0	0	568	1774
Rucker replay (routed through Guard)					0					0
RAF Lakenheath, UK	1	0	0	0	1	0	0	0	0	1
TACCSF, Kirtland AFB, NM	172	28	0	0	200	39	0	0	0	200
TBA, Pentagon, Washington, DC	12	3	0	0	15	0	0	0	0	15
TACTS, Cherry Point, NC	1	1	0	0	2	0	0	0	0	2
WISSARD, ANS Oceania	6	43	0	0	49	27	0	0	0	49
Total	1875	181	26	4	2086	72	0	0	570	2656
Percentages (%)	70.59	6.81	0.98	0.15	78.54	2.71	0.00	0.00	21.46	
*As recorded at WISSARD.										

Table B-5. Numbers of entities, by domain, by kind, at unencrypted sites: 11/6/94 from 0800–1000 GMT.

	Platform (1)					Munition (2)			Life-form (3)	
Site	**Land (1)**	**Air (2)**	**Ship (3)**	**Sub (4)**	**Sub-total**	**Anti-Air (1)**	**Anti-Armor (2)**	**Sub-total**	**Land (1)**	**Total**
SIMNET, Grafenwoehr, GE	60	0	0	0	60	0	0	0	2	62
BBS, Hohenfels, GE	637	21	0	0	658	4	11	15	255	928
CMTC–IS, Hohenfels, GE	566	9	0	0	575	0	0	0	77	652
Falcon Star, Grafenwoehr, GE	0	1	0	0	1	0	0	0	0	1
AVTB, Ft. Rucker, AL	0	8	0	0	8	0	10	10	0	18
Total	1263	39	0	0	1302	4	21	25	334	1661
Percentages (%)	76.04	2.00	0.00	0.00	78.00			2.00	20.00	

Table B-6. Numbers of entities, by domain, by kind, at encrypted sites: 11/6/94 from 1100–1300 GMT.

	Platform (1)					Munition (2)			Life-form (3)	
Site	Land (1)	Air (2)	Ship (3)	Sub (4)	Sub-total	Anti-Air (1)	Anti-Armor (2)	Sub-total	Land (1)	Total
*BFTT, Dam Neck, VA	5	0	17	1	23	0	0	0	0	23
AEGIS ship, Mayport, FL	0	0	1	0	1	0	0	0	0	1
IDA, Alexandria, VA	Viewport									
NAWC–AD, Patuxent River, MD	2	27	0	0	29	12	0	12	0	41
USAF Armstrong Lab, Mesa, AZ	0	2	0	0	2	0	0	0	0	2
*NSWC–DD, Dahlgren, VA	0	0	1	0	1	0	0	0	0	1
NUWC, Newport, RI	0	0	4	3	7	0	0	0	0	7
SEAF, Grafenwoehr, GE										
SIMNET (routed through Guard)	119	0	0	0	119	0	0	0	2	121
CMTC (routed through Guard)	569	9	0	0	578	0	0	0	80	658
BBS (routed through Guard)	534	8	0	0	542	0	0	0	229	771
Rucker replay (routed through Guard)	60	0	0	0	60	0	0	0	0	60
RAF Lakenheath, UK	0	1	0	0	1	0	0	0	0	1
TACCSF, Kirtland AFB, NM	162	13	0	0	175	12	0	12	0	187
TBA, Pentagon, Washington, DC	12	3	0	0	15	0	0	0	0	15
TACTS, Cherry Point, NC	3	2	0	0	7	0	0	0	0	7
WISSARD, NAS Oceania	1	72	0	0	73	58	0	58	0	131
Total	1467	137	25	4	1633	82	0	82	311	2026
Percentages (%)	72.41	6.76	1.23	0.20	80.60			4.05	15.35	
*As recorded at WISSARD.										

Table B-7. Numbers of entities, by domain, by kind, at unencrypted sites: 11/7/94 from 0800–1000 GMT.

	Platform (1)					Munition (2)			Life-form (3)	
Site	**Land (1)**	**Air (2)**	**Ship (3)**	**Sub (4)**	**Sub-total**	**Anti-Air (1)**	**Anti-Armor (2)**	**Sub-total**	**Land (1)**	**Total**
SIMNET, Grafenwoehr, GE	16	0	0	0	16	0	0	0	0	16
BBS, Hohenfels, GE	836	17	0	0	853	5	11	16	238	1107
CMTC–IS, Hohenfels, GE	551	7	0	0	558	0	0	0	89	647
Falcon Star, Grafenwoehr, GE					0			0		0
AVTB, Ft. Rucker, AL	8	0	0	0	8	0	26	26	0	34
Total	1411	24	0	0	1435	5	37	42	327	1804
Percentages (%)	78.22	1.33	0.00	0.00	79.55	0.28	2.05	2.33	18.13	

Table B-8. Numbers of entities, by domain, by kind, at encrypted sites: 11/7/94 from 1100–1300 GMT.

	Platform (1)					Munition (2)			Life-form (3)	
Site	**Land (1)**	**Air (2)**	**Ship (3)**	**Sub (4)**	**Sub-total**	**Anti-Air (1)**	**Anti-Armor (2)**	**Sub-total**	**Land (1)**	**Total**
*BFTT, Dam Neck, VA	6	0	22	0	28	0	0	0	0	28
AEGIS ship, Mayport, FL	0	0	1	0	1	1	0	1	0	2
IDA, Alexandria, VA	Viewport				0					0
NAWC–AD, Patuxent River, MD	1	49	0	0	50	11	0	11	0	61
USAF Armstrong Lab, Mesa, AZ	0	2	0	0	2	0	0	0	0	2
*NSWC–DD, Dahlgren, VA	0	0	1	0	1	6	0	6	0	7
NUWC, Newport, RI	0	1	4	3	8	0	0	0	0	8
SEAF, Grafenwoehr, GE								0		0
SIMNET (routed through Guard)	1	0	0	0	1	0	0	0	0	1
CMTC (routed through Guard)	555	7	0	0	562	0	0	0	79	641
BBS (routed through Guard)	688	10	0	1	698	0	0	0	214	912
Rucker replay (routed through Guard)	0	8	0	0	8	1	1	2	0	10
RAF Lakenheath, UK	0	1	0	0	1	0	0	0	0	1
TACCSF, Kirtland AFB, NM	Not available				0			0		0
TBA, Pentagon, Washington, DC					0			0		0
TACTS, Cherry Point, NC	1	1	0	0	2	0	0	0	0	2
WISSARD, ANS Oceania	1	18	0	0	19	13	0	13	0	32
Total	1253	97	28	3	1381	32	1	33	293	1707
Percentages (%)	73.40	5.68	1.64	0.18	80.90	1.87	0.06	1.93	17.16	
*As recorded at WISSARD.										

APPENDIX C
PDU PERCENTAGES

Table C-1. PDU percentages for 4 November 1994.

Site	Entity State (%)	Fire (%)	Detona-tion (%)	Collision (%)	Exper-imental (%)
SIMNET, Grafenwoehr, GE	99.7	0.1	0.1	0.0	0.0
BBS, Hohenfels, GE	64.8	trace	1.2	0.0	34.0
CMTC–IS, Hohenfels, GE	97.5	1.5	1.5	0.0	0.0
Falcon Star, Grafenwoehr, GE	100.0	0.0	0.0	0.0	0.0
AVTB, Ft. Rucker, AL	93.7	0.3	0.5	4.4	0.0
NAWC–AD, Patuxent River, MD	100.0	0.0	0.0	0.0	0.0
NUWC, Newport, RI	100.0	trace	0.0	0.0	0.0
RAF Lakenheath, UK	100.0	0.0	0.0	0.0	0.0
TACCSF, Kirtland AFB, NM	100.0	trace	trace	0.0	0.0
TACTS, Cherry Point, NC	94.7	0.4	0.4	0.0	0.0
WISSARD, NAS Oceania	96.5	trace	trace	0.0	0.0

Table C-2. PDU percentages for 5 November 1994.

Site	Entity State (%)	Fire (%)	Detona-tion (%)	Collision (%)	Exper-imental (%)
SIMNET, Grafenwoehr, GE	100.0	trace	trace	0.0	0.0
BBS, Hohenfels, GE	65.0	trace	trace	0.0	35.0
CMTC–IS, Hohenfels, GE	99.7	0.2	0.2	0.0	0.0
Falcon Star, Grafenwoehr, GE	100.0	0.0	0.0	0.0	0.0
AVTB, Ft. Rucker, AL	95.4	2.3	2.3	0.0	0.0
NAWC–AD, Patuxent River, MD	99.9	trace	trace	0.0	0.0
NUWC, Newport, RI	100.0	trace	trace	0.0	0.0
RAF Lakenheath, UK	100.0	0.0	0.0	0.0	0.0
TACCSF, Kirtland AFB, NM	100.0	0.0	0.0	0.0	0.0
TACTS, Cherry Point, NC	99.9	trace	trace	0.0	0.0
WISSARD, NAS Oceania	92.3	trace	trace	0.0	0.0

Table C-3. PDU percentages for 6 November 1994.

Site	Entity State (%)	Fire (%)	Detona-tion (%)	Collision (%)	Exper-imental (%)
SIMNET, Grafenwoehr, GE	100.0	0.0	0.0	0.0	0.0
BBS, Hohenfels, GE	57.6	0.0	0.3	0.0	42.0
CMTC–IS, Hohenfels, GE	100.0	0.0	0.0	0.0	0.0
Falcon Star, Grafenwoehr, GE	100.0	trace	trace	0.0	0.0
AVTB, Ft. Rucker, AL	89.7	4.5	5.8	0.0	0.0
NAWC–AD, Patuxent River, MD	99.3	trace	0.0	0.0	0.0
NUWC, Newport, RI	100.0	0.0	0.0	0.0	0.0
RAF Lakenheath, UK	100.0	trace	0.0	0.0	0.0
TACCSF, Kirtland AFB, NM	94.8	trace	trace	0.0	0.0
TACTS, Cherry Point, NC	98.7	0.7	0.0	0.0	0.0
WISSARD, NAS Oceania	94.4	trace	trace	0.0	0.0

Table C-4. PDU percentages for 7 November 1994.

Site	Entity State (%)	Fire (%)	Detona-tion (%)	Collision (%)	Exper-imental (%)
SIMNET, Grafenwoehr, GE	99.5	0.3	0.3	0.0	0.0
BBS, Hohenfels, GE	62.0	trace	trace	0.0	38.0
CMTC–IS, Hohenfels, GE	98.3	0.9	0.8	0.0	0.0
Falcon Star, Grafenwoehr, GE	100.0	0.0	0.0	0.0	0.0
AVTB, Ft. Rucker, AL	97.8	0.3	1.9	0.0	0.0
NAWC–AD, Patuxent River, MD	99.9	0.1	0.0	0.0	0.0
NUWC, Newport, RI	100.0	0.0	0.0	0.0	0.0
RAF Lakenheath, UK	100.0	0.0	0.0	0.0	0.0
TACCSF, Kirtland AFB, NM					
TACTS, Cherry Point, NC	99.3	0.4	0.4	0.0	0.0
WISSARD, NAS Oceania	87.5	0.0	0.0	0.0	0.0

APPENDIX D
LOAD SUMMARY INFORMATION

Table D-1. STOW–E summary information for 4–6 November 1994.

	ESPDU/sec/entity			AG Reduction Factor (Kbps)			AG Reduction Factor (pps)		
	25%	50%	75%	25%	50%	75%	25%	50%	75%
PLATFORMS (Kind=1)									
Land (Domain=1)									
Live									
CMTC	0.20	0.20	0.20	125.00	600.00	800.00	750.00	4700.00	8200.00
Virtual									
SIMNET	0.60	0.80	1.10	3.40	6.20	8.20	20.00	36.00	47.00
Constructive									
BBS	0.20	0.20	0.50	4.40	6.30	11.30	29.00	38.00	74.00
Cherry Pt.	0.20	0.20	0.20						
TBA, Pentagon	0.02	0.03	0.05						
TACCSF	0.20	0.20	0.20						
WISSARD	0.10	0.30	0.60						
Pax	0.02	0.03	0.10						
Rucker	0.20	0.40	0.50	3.20	3.50	6.80	18.00	19.00	20.00
Air (Domain=2)									
Live									
CMTC	0.20	0.20	0.20	34.00	60.00	80.00	235.00	500.00	900.00
Cherry Pt.	0.40	0.80	1.20						
Virtual									
SIMNET	0.20	0.20	0.20	43.00	45.00	45.00	300.00	313.00	313.00
Falcon Star	0.50	0.80	1.70	1.40	1.40	1.50	9.50	9.70	10.10
RAF Laken	8.60	8.90	9.20						
TBA, Pentagon	1.20	3.40	7.80						
Armstrong	0.20	0.20	2.00						
Rucker	0.20	0.20	1.10	5.10	13.90	18.40	36.00	100.00	124.00

Table D-1. STOW–E summary information for 4–6 November 1994 (Continued).

	ESPDU/sec/entity			AG Reduction Factor (Kbps)			AG Reduction Factor (pps)		
	25%	50%	75%	25%	50%	75%	25%	50%	75%
Constructive									
BBS	0.20	0.20	0.60	2.60	10.80	46.00	15.00	36.00	319.00
*Pax River	0.04	0.05	0.10						
*TACCSF	0.20	0.20	0.30						
*WISSARD	2.70	4.40	9.10						
* Includes some virtual entities.									
Surface (Domain=3)									
Constructive									
Newport	0.20	0.30	0.40						
Cherry Point	0.20	0.20	0.20						
Subsurface (Domain=4)									
Virtual									
Newport	0.20	0.30	0.50						
LIFEFORM (Kind=3)									
Land (Domain=1)									
Live									
CMTC	0.20	0.20	0.20	40.00	240.00	355.00	275.00	1700.00	2460.00
Virtual									
SIMNET	0.40	0.70	1.40	2.70	2.80	3.10	15.00	16.00	17.00
Constructive									
BBS	0.20	0.20	0.20	7.40	12.10	250.00	52.00	83.00	526.00
MUNITIONS (Kind=2)									
Anti-Air (Domain=1)									
Armstrong	5.00	5.00	5.00						
BBS	0.20	0.50	0.80	2.00	2.10	2.30	13.00	13.00	13.70
Falcon Star	1.00	2.10	13.60						
Pax	0.10	0.20	0.30						

Table D-1. STOW–E summary information for 4–6 November 1994 (Continued).

	ESPDU/sec/entity			AG Reduction Factor (Kbps)			AG Reduction Factor (pps)		
	25%	50%	75%	25%	50%	75%	25%	50%	75%
TACCSF	0.20	0.60	1.10						
WISSARD	1.00	3.50	7.60						
Anti-Armor (Domain=2)									
BBS	0.20	0.80	1.20		2.00			13.00	13.90
Rucker	0.40	1.00	1.20		2.00				

APPENDIX E
PREDICTION WORKSHEET

Table E-1. STOW–E load estimates based on empirical STOW–E data.

UNCLASSIFIED SITES:								
				75% Tax Rate	Articu-lated	Total	Total PDU	Total
Vehicle	**Graf**	**Rucker**	**Total**	**ESPDU/s/Ent**	**Parts**	**ESPDU PPS**	**PPS**	**Kbps**
Submarine			0	0.50	0	0.00	0.00	0.00
Ship			0	0.40	4	0.00	0.00	0.00
FWA			0	1.70	0	0.00	0.00	0.00
RWA	40	8	48	1.10	0	52.80	53.33	82.77
Tank	998		998	0.50	2	499.00	504.04	911.31
Truck	505		505	0.50	0	252.50	255.05	395.84
DI	90		90	0.50	0	45.00	45.45	70.55
Subtotal	1633	8	1641			849.30	857.88	1460.46
Site Kbps	1476.49	14.08						
Site pps	903.76	9.46						

Table E-1. STOW–E load estimates based on empirical STOW–E data (Continued).

CLASSIFIED SITES:														75% Tx Rate	Artic-u-lated	Total	Total PDU	Total
Vehi-cle	Cherry Pt	Dam Neck	Kirt-land	May-port	New-port	Oceana	Pax River	Pen-tagon	Arms-trong	Dahl-gren	Lak–en-heath	Span g-dah-lem	Total	ESPDU (pps)	Parts	ESPDU (pps)	pps	Kbps
Sub-marine		13			4								17	0.50	0	8.50	8.59	13.33
Ship		26		1	1		1			1			28	0.40	4	11.20	11.31	23.35
FWA	4	5	48			14	23	1	4		1	2	102	1.70	0	173.40	175.15	271.84
RWA		2					3						5	1.10	0	5.50	5.56	8.62
Tank			68			33							101	0.50	2	50.50	51.01	92.23
Truck			23										23	0.50	0	11.50	11.62	18.03
DI													0	0.50	0	0.00	0.00	0.00
Sub-total	4	46	139	1	5	47	27		4	1	1	2	276			260.60	263.23	427.39
Site Kbps	10.88	49.65	212.33	0.85	4.05	68.83	68.69	2.72	10.88	0.85	2.72	5.44						
Site pps	7.31	29.68	136.67	0.43	2.58	43.33	46.02	1.83	7.31	0.43	1.83	3.66						
STOW–E HIGHEST OFFERED LOAD TO THE NETWORK (All Black + Euro Black + Euro Red): 2912.33 Kbps																		

Table E-2. STOW–E load estimates based on CADIS and Firestarter data.

UNCLASSIFIED SITES:										
				Low Tax Rate	High Tax Rate	Avg Tax Rate	Arti-cu-lated	Total	Total PDU	Total
Vehicle	**Graf**	**Rucker**	**Total**	**ESPDU/s/Ent**	**ESPDU/s/Ent**	**ESPDU/s/Ent**	**Parts**	**ESPDU/PPS**	**PPS**	**Kbps**
Submarine			0	0.20	0.20	0.20	0	0.00	0.00	0.00
Ship			0	1.00	1.00	1.00	4	0.00	0.00	0.00
FWA			0	2.10	11.20	3.92	0	0.00	0.00	0.00
RWA	40	8	48	2.00	2.00	2.00	0	96.00	103.23	153.60
Tank	998		998	0.70	0.70	0.70	2	698.60	751.18	1302.13
Truck	505		505	0.70	0.70	0.70	0	353.50	380.11	565.60
DI	90		90	0.70	0.70	0.70	0	63.00	67.74	100.80
Subtotal	1633	8	1641						1302.26	2122.13
Site Kbps	2096.53	25.60								
Site pps	1285.05	17.20								

Table E-2. STOW–E load estimates based on CADIS and Firestarter data (Continued).

SECRET NO FOREIGN:																		
														Low Tx Rate	High Tx Rate	Avg Tx Rate	Artic-ulated	Total
Vehi-cle	Cherry Pt	Dam Neck	Kirt-land	May-port	New-port	Oceana	Pax River	Pen-tagon	Arms-trong	Dahl-gren	Lak–en-heath	Spang-dah-lem	Total	ESPDU PPS	ESPDU PPS	ESPDU PPS	Parts	ESPDU PPS
Sub-marine		13			4								17	0.20	0.20	0.20	0	3.40
Ship		26		1	1		1			1			28	1.00	1.00	1.00	4	28.00
FWA	4	5	48			14	23	1	4		1	2	102	2.10	11.20	3.92	0	399.84
RWA		2					3						5	2.00	2.00	2.00	0	10.00
Tank			68			33							101	0.70	0.70	0.70	2	70.70
Truck			23										23	0.70	0.70	0.70	0	16.10
DI													0	0.70	0.70	0.70	0	0.00
Sub-total	4	46	139	1	5	47	27		4	1	1	2	276					528.04
Site Kbps	25.09	97.24	415.54	2.13	3.41	130.86	155.98	6.27	25.09	2.13	6.27	12.54						
Site pps	16.86	56.13	270.82	1.08	1.94	83.85	104.47	4.22	16.86	1.08	4.22	8.43						

APPENDIX F
PDU DELAYS

Table F-1. STOW–E PDU propagation delays for 4–6 November, Rucker/SIMNET.

			Mean Delays	
Date	Time-Range	Rucker AG (seconds)	DSI (seconds)	SIMNET AG (seconds)
4 Nov	08:39–09:13	1.03	0.13	0.23
5 Nov	09:05–09:28	0.25	0.19	0.21
6 Nov	09:12–09:26	0.46	0.14	1.51
	09:32–09:38	0.29	0.13	0.18

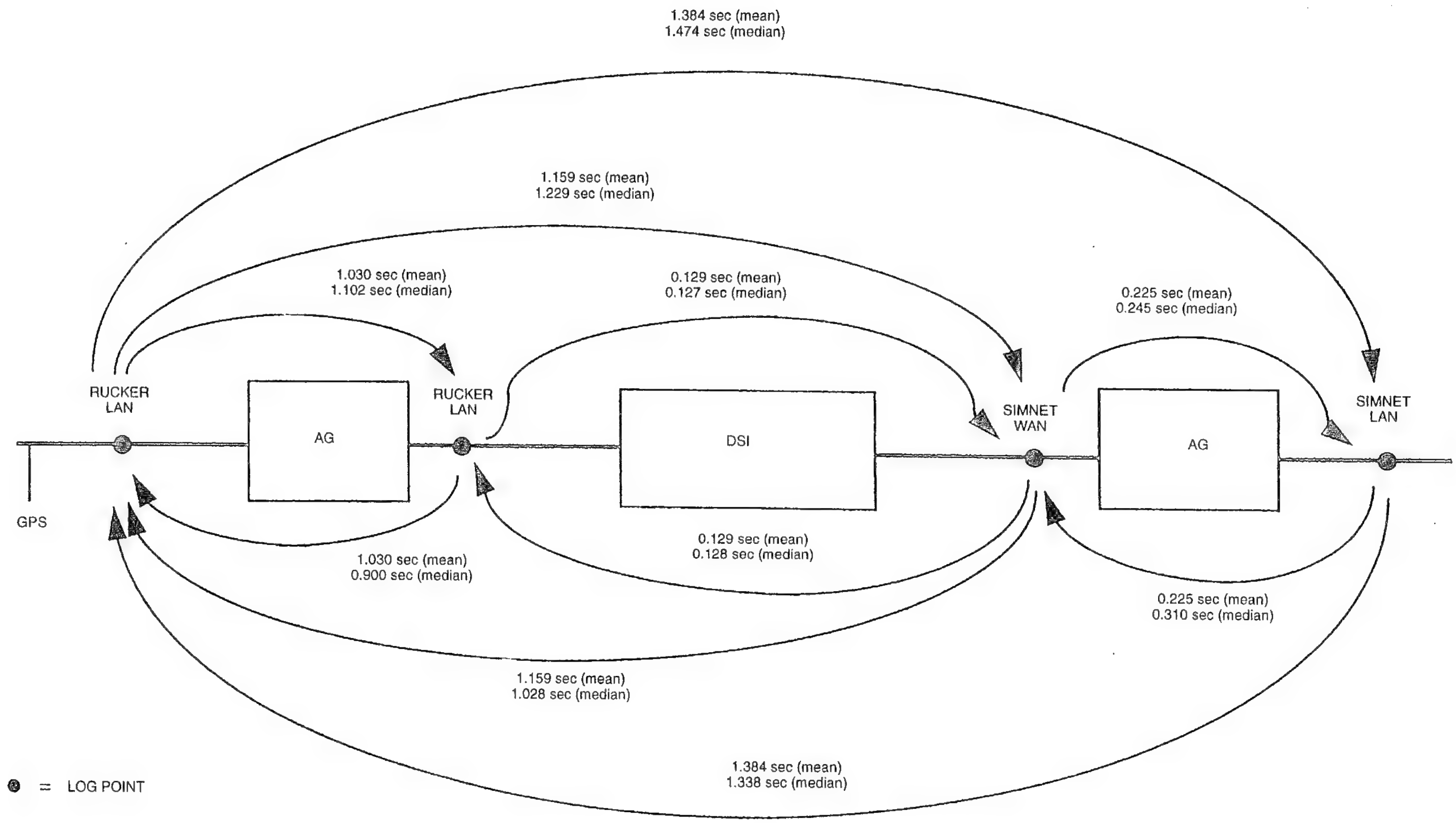

Figure F-1. PDU delay information between Rucker and SIMNET on 4 November 1994, 08:39–09:13 GMT.

Table F-2. PDU entity counts between Rucker and SIMNET on 4 November 1994, 08:39–09:13 GMT.

Rucker to SIMNET Entity Counts*		SIMNET to Rucker Entity Counts*	
EntityStatePDU	3	EntityStatePDU	0
FirePDU	0	FirePDU	0
DetonationPDU	0	DetonationPDU	0
ServiceRequestPDU	384	ServiceRequestPDU	7
Total	387	Total	7
*Entity counts represent all PDUs, for the above time-range, which were detected at al four log-points.			

Table F-3. PDU load information between Rucker and SIMNET on 4 November 1994, 08:39–09:13 GMT.

Rucker				
		LAN Kbps	**LAN pkts/sec**	**WAN Kbps**
	Mean	1.84	0.20	0.24
	Median	1.87	0.20	0.22
	Standard deviation	0.15	0.01	0.11
SIMNET				
	Mean	590.50	321.46	55.01
	Median	581.87	324.01	52.88
	Standard deviation	51.87	34.01	17.16

NOTES:

- Rucker PDUs are those with site = 4 only
- SIMNET PDUs are those with site = 6 only
- The Rucker LAN had a GPS time-server
- Both logger machines at SIMNET were set approximately 1 hour fast
- All delays include at least one logger processing delay
- “to times (mean)” equal “from times (mean)” due to time-correction algorithm.

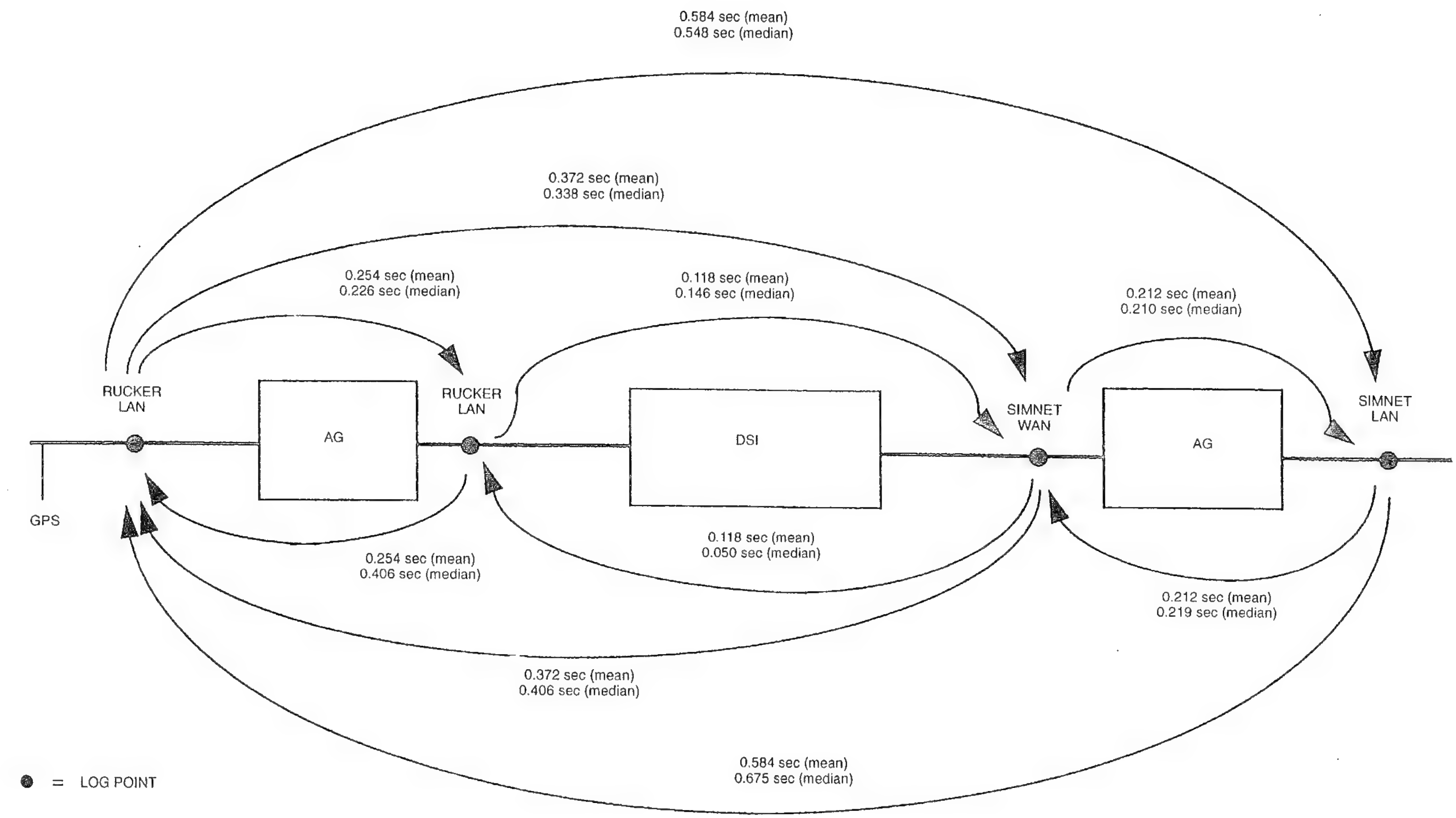

Figure F-2. PDU delay information between Rucker and SIMNET on 5 November 1994, 09:05–09:28 GMT.

Table F-4. PDU delay information between Rucker and SIMNET on 5 November 1994, 09:05–09:28 GMT.

Rucker to SIMNET Entity Counts*		SIMNET to Rucker Entity Counts*	
EntityStatePDU	42	EntityStatePDU	14
FirePDU	799	FirePDU	37
DetonationPDU	804	DetonationPDU	0
Total	1645	Total	51
*Entity counts represent all PDUs, for the above time-range, which were detected at al four log-points.			

Table F-5. PDU load information between Rucker and SIMNET on 5 November 1994, 09:05–09:28 GMT.

Rucker				
		LAN Kbps	**LAN pkts/sec**	**WAN Kbps**
	Mean	11.18	8.88	4.42
	Median	10.16	8.35	3.35
	Standard deviation	3.82	2.71	2.64
SIMNET				
	Mean	444.54	283.76	25.93
	Median	432.56	284.82	25.41
	Standard deviation	30.56	17.76	4.76

NOTES:

- Rucker PDUs are those with site = 4 only
- SIMNET PDUs are those with site = 6 only
- The Rucker LAN had a GPS time-server
- Both logger machines at SIMNET were set approximately 1 hour fast
- All delays include at least one logger processing delay
- "to times (mean)" equal "from times (mean)" due to time-correction algorithm.

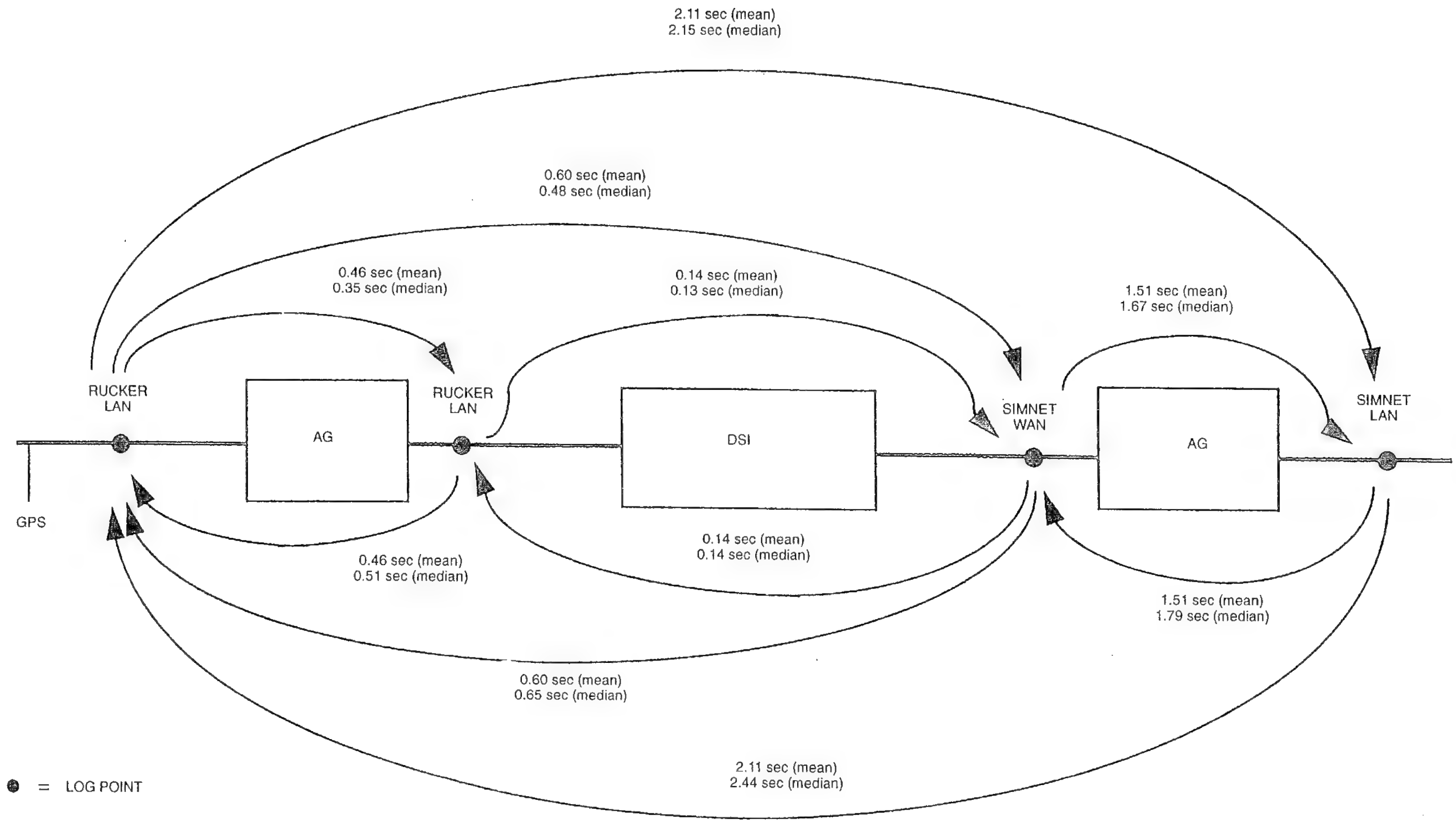

Figure F-3. PDU delay information between Rucker and SIMNET on 6 November 1994, 09:12–09:26 GMT.

Table F-6. PDU delay information between Rucker and SIMNET on 6 November 1994, 09:12–09:26 GMT.

Rucker to SIMNET Entity Counts*		SIMNET to Rucker Entity Counts*	
EntityStatePDU	14	EntityStatePDU	9
FirePDU	336	FirePDU	
DetonationPDU	335	DetonationPDU	
ServiceRequestPDU		ServiceRequestPDU	
Total	685	Total	9
*Entity counts represent all PDUs, for the above time-range, which were detected at al four log-points.			

Table F-7. PDU load information between Rucker and SIMNET on 6 November 1994, 09:12–09:26 GMT.

Rucker				
		LAN Kbps	**LAN pkts/sec**	**WAN Kbps**
	Mean	9.7	8.8	insufficient WAN data
	Median	8.0	7.0	insufficient WAN data
	Standard deviation	3.9	3.6	insufficient WAN data
SIMNET				
	Mean	644.7	431.1	42.1
	Median	639.1	426.2	42.7
	Standard deviation	23.6	17.0	8.2

NOTES:

- Rucker PDUs are those with site = 4 only
- SIMNET PDUs are those with site = 6 only
- The Rucker LAN had a GPS time-server
- Both logger machines at SIMNET were set approximately 1 hour fast
- All delays include at least one logger processing delay
- "to times (mean)" equal "from times (mean)" due to time-correction algorithm.

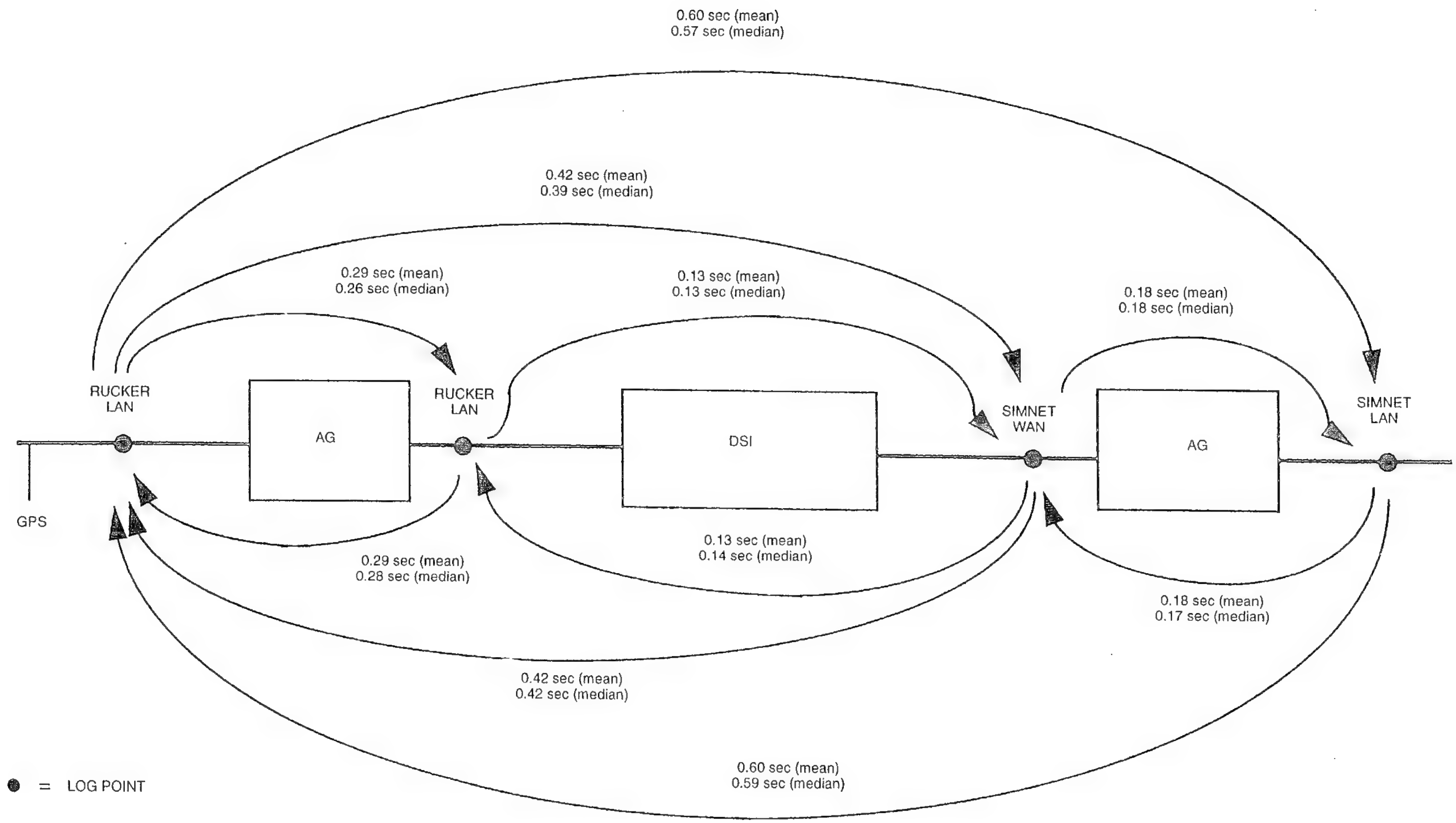

Figure F-4. PDU delay information between Rucker and SIMNET on 6 November 1994, 09:32–09:38 GMT.

Table F-8. PDU delay information between Rucker and SIMNET on 6 November 1994, 09:32–09:38 GMT.

Rucker to SIMNET Entity Counts*		SIMNET to Rucker Entity Counts*	
EntityStatePDU	4	EntityStatePDU	9
FirePDU	1094	FirePDU	
DetonationPDU	1651	DetonationPDU	
ServiceRequestPDU		ServiceRequestPDU	
Total	2749	Total	9
*Entity counts represent all PDUs, for the above time-range, which were detected at al four log-points.			

Table F-9. PDU load information between Rucker and SIMNET 6 November 1994, 09:32–09:38 GMT.

Rucker				
		LAN Kbps	**LAN pkts/sec**	**WAN Kbps**
	Mean	16.4	16.2	insufficient WAN data
	Median	17.3	15.8	insufficient WAN data
	Standard deviation	6.4	7.9	insufficient WAN data
SIMNET				
	Mean	677.8	454.2	59.4
	Median	679.3	456.0	59.5
	Standard deviation	12.8	8.9	3.8

NOTES:

- Rucker PDUs are those with site = 4 only
- SIMNET PDUs are those with site = 6 only
- The Rucker LAN had a GPS time-server
- Both logger machines at SIMNET were set approximately 1 hour fast
- All delays include at least one logger processing delay
- “to times (mean)” equal “from times (mean)” due to time-correction algorithm.

Table F-10. PDU load information between Newport, Kirtland, and Pax.

			Delays (seconds)				PDU Counts				
Sites	Date	Time (GMT)	Mean	Median	Max	Min	Entity	Det	Fire	Ser-vice	Emis-sion
Newport to Pax	6 Nov.	11:00–12:59	3.07	2.65	44.70	–0.01	4459	0	0	0	0
Newport to Kirtland	6 Nov.	11:00–12:48	3.37	2.88	13.82	0.02	2919	0	0	0	0
Kirtland to Pax	6 Nov.	11:01–12:11	5.03	4.98	13.37	0.30	16346	20	18	0	0
Kirtland to Newport	6 Nov.	11:01–12:48	1.02	0.91	6.37	–0.27	7823	27	26	0	64
Pax to Newport	6 Nov.	*									
Pax to Kirtland	6 Nov.	*									

*A simulation at Pax was putting out duplicate PDUs.
The current state of our tools cannot differentiate between these PDUs and, thus, delay cannot be measured from Pax.

NOTES: There were no WANloggers.
Only end-to-end delays.
GPS receivers at Newport, Kirtland, and Pax; no time-correction performed.

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13. ABSTRACT *(Maximum 200 words)*

The Synthetic Theater of War-Europe (STOW-E) distributed simulation demonstration was conducted 4–7 November 1994. This exercise linked 16 sites around the world in a single virtual battlespace. Live, virtual, and constructive forces representing all four Department of Defense (DoD) services participated in a joint operation involving land, sea, and air engagements. This report provides the following technical analysis of STOW-E: Application Gateway (AG) performance, characterization of generated Distributed Interactive Simulation (DIS) traffic, and observed network traffic delays and losses.

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